FEASIBILITY OF COLD WEATHER EARTHWORK IN INDIANA

JUNE 1967

NO. 15

by

A. M. OSBORNE

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

FEASIBILITY OF COLD WEATHER EARTHWORK IN INDIANA

TO: G. A. Leonards, Director
Joint Highway Research Project

June 20, 1967

File: 6-14-8

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-36H

A Final Report "Feasibility of Cold Weather Earthwork in Indiana" by Alfred M. Osborne, Graduate Assistant in Research on our staff is presented to the Board for the record. The research has been directed by Professor C. W. Lovell, Jr. of our staff and was also used by Mr. Osborne for his MSCE thesis.

The effects of cold and inclement weather on men, machines and materials involved in highway earthwork are reviewed and the increased costs of various earthwork operations in Indiana in cold weather have been estimated. The probable benefits of such operations have also been evaluated and by a hypothetical example shows that cold weather earthwork is feasible on an Interstate highway construction project in northern Indiana and that year-round construction can produce an economic benefit.

The report is presented to the Board as fulfillment of the Plan of Study approved by the Board on October 29, 1965.

Respectfully submitted,

Harold L. Michael/jgs
Harold L. Michael
Associate Director

HLM:jgs

Attachment

Copy:

F. L. Ashbaucher	V. E. Harvey	M. B. Scott
W. L. Dolch	J. F. McLaughlin	W. T. Spencer
W. H. Goetz	F. B. Mendenhall	F. W. Stubbs
W. L. Grecco	R. D. Miles	H. R. J. Walsh
G. K. Hallock	J. C. Oppenlander	K. B. Woods
R. H. Harrell	C. F. Scholer	E. J. Yoder

Final Report

FEASIBILITY OF COLD WEATHER EARTHWORK IN INDIANA

by

Alfred M. Osborne
Graduate Assistant in Research

Joint Highway Research Project

File No.: 6-14-8

Project No.: C-36-36H

Purdue University

Lafayette, Indiana

June 20, 1967

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Dr. C. W. Lovell, Jr., Associate Professor of Civil Engineering, Purdue University, for his assistance and guidance during the course of this investigation and the preparation of this thesis.

Financial assistance which made this investigation possible was provided by the Joint Highway Research Project, to which the writer is deeply grateful.

The writer also wishes to express sincere thanks to the following persons who gave assistance in many special ways: Dr. J. A. Havers, Associate Professor of Civil Engineering, Purdue University, for his advice on the construction methods and economics; Mr. W. T. Spencer, Head of the Bureau of Materials and Tests, Indiana State Highway Commission, for his advice on highway construction policies in Indiana; and to Dr. Dan Wiersma, Professor of Agronomy, and Mr. Hank J. Bauer, graduate student in Agronomy, Purdue University, for their advice on the soil moisture studies.

In addition,special thanks are due to my wife Beth who undertook the painstaking proofreading of this manuscript.

TABLE OF CONTENTS

Page

LIST OF TABLES v

LIST OF FIGURES vi

ABSTRACT vii

INTRODUCTION 1

Seasonal Influence in Current Practice 1
Purpose and Scope of Study 2

REVIEW OF THE LITERATURE 4

Cold Weather Effects on Workmen 4
Cold Weather Effects on Soils 7
Cold Weather Effects on Machines 8

PRESENT STATE OF COLD WEATHER EARTHWORK PRACTICE 12

Northern United States 12
Excavation and Placement 12
Compaction 17
Contractors in Indiana 19
Canadian Provinces and Alaska 23
Southeastern United States 25
Scandinavian Countries 27

PROSPECTS FOR COLD WEATHER EARTHWORK IN INDIANA 41

Effects on People 41
Effects on Construction Equipment and Methods 43
Effects on Soils 46
Other Materials 53
Economic Feasibility 56
Size of Projects 61
Example of Benefit Calculation 61

SUMMARY 65

CONCLUSIONS 66

RECOMMENDATIONS FOR FURTHER STUDY 68

BIBLIOGRAPHY 70

TABLE OF CONTENTS (cont'd.)

Page

APPENDIX A - COLD WEATHER EARTHWORK QUESTIONNAIRE TO HIGHWAY DEPARTMENTS 78

APPENDIX B - COLD WEATHER EARTHWORK QUESTIONNAIRE TO CONTRACTORS . . 80

APPENDIX C - INFLUENCE OF TEMPERATURE ON COMPACTION OF SELECTED INDIANA SOILS 81

LIST OF TABLES

Table		Page
1.	Relative Working Efficiency of Manual Laborers	6
2.	Relative Efficiency of Operation of Construction Machinery	11
3.	Northern States' Answers to Cold Weather Earthwork Questionnaire	13
4.	Contractors' Replies to Cold Weather Earthwork Questionnaire	21
5.	Canadian and Alaskan Answers to Cold Weather Earthwork Questionnaire	24
6.	Relative Cost of Construction Operations in Different Seasons in Different Areas	30
7.	Answers to Questions Concerning Performing Certain Construction Operations in Different Seasons	35
8.	Increase in Cost Caused by Excavation in Frost Compared to Insulation Against Frost	37
9.	Summary of Cost Changes Caused by Different Construction Seasons	40
10.	Windchill Values in Indiana During Fall, Winter, and Spring Months	42
11.	Summary of Economic Benefits Derived from Finishing One Month Earlier by Working Two Months Longer	62
12.	Total Benefits Due to Cold Weather Earthwork Compared to Monthly Average Construction Cost for Different Lengths of Working Season	64
13.	Index Properties and Classification of Maumee "B" and Miami "B" Soils	81

LIST OF FIGURES

Figure | Page

1. Graph of Windchill related to Temperature and Surface Wind Velocity 5
2. Effect of Temperature on Compaction of Different Soils . . . 9
3. Locations where Frozen Soil Can be Used Without Detrimental Effects 15
4. Contours for Maximum Shear, $\tau_{max}/\gamma H$ 16
5. Embankment Profiles, Warm Weather vs. Cold Weather Lifts in Rolled Fills 18
6. State of Winter Earthwork in the Northern U. S. 20
7. Contractors' Winter Experience in Indiana 22
8. State of Winter Earthwork Practice in Canada and Alaska . . . 26
9. Areas of Sweden and the United States Having Similar Climates 29
10. Percent of Time When Severe Windchill Occurs 44
11. Map of Indiana Showing Sand and Gravel Deposits 47
12a. Locations of Soil Samples Used in Analysis. 50
12. Map of Indiana Showing Physiographic Units and Glacial Boundaries 51
13. Selected Water Content Variations of Indiana Soils 52
14. Yearly Variation in Natural Water Content - I 54
15. Yearly Variation in Natural Water Content - II 55
16. Influence of Temperature on Compaction - I 83
17. Influence of Temperature on Compaction - II 84

ABSTRACT

Osborne, Alfred M., MSCE, Purdue University, May, 1967. Feasibility of Cold Weather Earthwork in Indiana, Major Professor: C. W. Lovell, Jr.

The effects of cold and inclement weather on men, machines, and materials involved in highway earthwork have been reviewed.

The cold weather earthwork experience of the northern states of the United States, the provinces of Canada, and the Scandinavian countries has been reviewed with the aim of determining, (1) how weather and soil conditions tend to restrict the length of the construction season, and (2) what cold weather construction practices might be applicable in Indiana. The seasonal variations of weather and certain soil conditions in Indiana have been studied.

The increased costs of various earthwork operations in Indiana during cold weather have been estimated. The probable benefits of (1) reduced interest and inflation costs, (2) reduced accident and inconvenience costs, and (3) better utilization of the resources of labor, contractors, and the State Highway Commission have been weighed against heightened technological demands.

A hypothetical example has been developed which shows that cold weather earthwork is feasible on an Interstate highway construction project in northern Indiana and that year-round construction scheduling can produce an economic benefit.

INTRODUCTION

Seasonal Influence in Current Practice

Until a few decades ago, cold weather earthwork[1] was strictly avoided in highway construction. The requisite technology was recognized to be more complex and costly in the winter, and this factor was presumed to override the benefits that could be derived from earlier completion dates, continuous use of construction forces and equipment, and the like.

As demand for new highway facilities has increased, some penetrations into the traditional cold weather shutdown have been accomplished. These developments have been mostly concentrated in the colder regions, where the time duration of the poor weather has the most restrictive effect. Improvements in earth-handling equipment have played an important role. The Canadian provinces have accumulated much valuable cold weather technology. European experience also provides insight. For example, in Sweden "...during October to March, 18 million cubic yards of earthwork for highways is done, and during April to September, 9 million cubic yards" (89)[2].

The feasibility of "stretching" the construction season is also a matter of interest in the warmer regions, where the unfavorable temperatures are of shorter duration. The interest of the Indiana State Highway Commission (ISHC) in cold weather earthwork has found expression in

1. The term "earthwork" is used in a comprehensive manner to include any excavation, handling, placement, or compaction operation with any "earthen" material...soil, rock, peat.
2. Numbers refer to items in the Bibliography, page 70 .

limited previous experimental effort[1], and it is the continuing concern of the Commission which has made possible this feasibility study.

In long range and total perspective, the need is for development of design and construction technology which will permit year-round earthwork operations in all climates and under almost every meteorological variation.

Purpose and Scope of Study

The purpose of this study was to determine the technical and economical feasibility of doing earthwork in Indiana during the cold season, whereby the elapsed time for highway construction could be reduced and the rate at which modern highways are put into service could be accelerated.

The specific points studied were:

1. the experience which other countries and other states of the United States have had with cold weather earthwork;
2. the experience which contractors operating in Indiana have had with cold weather earthwork;
3. the weather and soil conditions which cause earthwork to be stopped for the winter;
4. the seasonal variation in weather and soil conditions in Indiana;
5. the seasonal effects on construction workers and machinery in Indiana;
6. the increased costs of doing cold weather earthwork in Indiana; and
7. the benefits which can accrue from doing cold weather earthwork in Indiana.

---

1. Personal communication with W. T. Spencer, Chief, Division of Materials and Tests, ISHC.

The background and perspective gained in this study permit formulation of a logical "next step" in research designed to make cold weather earthwork a practical alternate to current practice.

REVIEW OF THE LITERATURE

Cold Weather Effects on Workmen

The U. S. Army (22) has found that the elements which govern the comfort, and therefore the efficiency, of workmen in cold weather are air temperature, surface wind velocity, and relative humidity. Air temperature and surface wind velocity are often combined to yield a "windchill" index, which can then be correlated with working efficiency. Figure 1 shows windchill under dry, shaded conditions. If the relative humidity is over 90%, the windchill will be greater than that shown. On the other hand, if the sun is shining, the windchill will be less than that shown.

The reactions of different people to conditions characterized by a given value of the windchill index depend on the physical condition and degree of acclimatization of the individuals. Men who have been exposed to relatively high windchills for a few weeks suffer a lesser loss of efficiency than those accustomed to more comfortable surroundings (5).

A study made by interviewing a number of Swedish contractors and engineers (6) has produced the consensus of opinion shown in Table 1, relative to the efficiency of the average construction worker as affected by air temperature, light conditions, and precipitation. The three parts of Table 1 are combined for a given condition of air temperature, light, and precipitation by multiplying the working efficiencies shown. For example, at a temperature of 15°F at dusk with a light snow falling, the

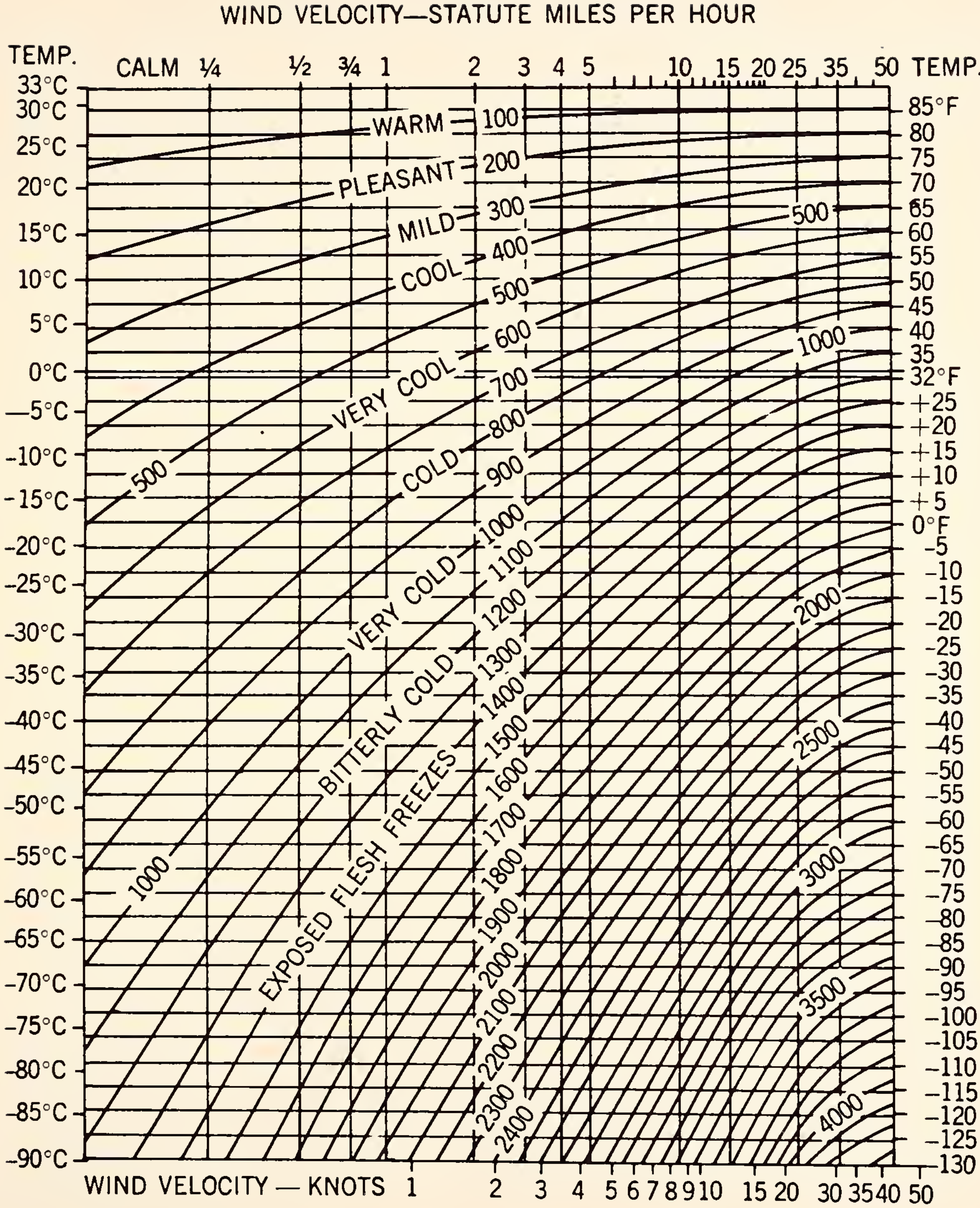


Figure 1. *Graph of windchill related to temperature and surface-wind velocity.* (FROM 22)

Table 1

Relative Working Efficiency of Manual Laborers (6)

Weather Factor	Working Efficiency (%)
Air temperature (°F):	
85	72
70	95
50	100
40	98
32	97
25	95
15	88
- 5	73
- 25	33
Light Condition:	
Bright Sunshine	97
Indirect Sunshine	100
Dusk	92
Subarctic Winter Twilight	56
Precipitation:	
Heavy Rain	36
Light Rain	89
Dry, Temperature 50°F	100
Light Snow	90
Heavy Snow	41

working efficiency for manual laborers is (0.88)(0.92)(0.90) = 0.73. Note that only reasonable combinations can be used. For example, bright sunshine obviously cannot occur in combination with heavy snow or rain.

Cold Weather Effects on Soils

The major cold weather effect is the freezing of soil water. The consequence is a great strengthening of the soil mass, which continues as the temperature decreases. Tests performed by Lovell (63) show that the compressive strength of partly-frozen, fine-grained soil is highly temperature dependent. For example, samples of silty clay compacted at approximately Standard AASHO optimum water content, showed strengths[1] 4.1 times as great at - 4°F as at 23°F. This is due in part to the greater percentage of soil water frozen at - 4°F. Considering a natural soil frozen to a depth of a few inches, the coldest part of the frozen layer (normally the surface) will be considerably stronger than that portion which is at a temperature just slightly below freezing. Thus, if the coldest, strongest portion of the partly frozen layer can be penetrated in the process of excavation, the remainder of the layer can be excavated with decreasing difficulty. Should the frozen depth be more than a few inches, excavation becomes a major problem.[2]

A secondary cold weather effect is the high water content of thawing and recently thawed soils. This effect is supplemented by spring rains and magnified by low evaporation rates in the later winter and early spring.

Certain chemicals can be mixed with soil to prevent or suppress freezing and to prevent detrimental frost action in soil due to the formation of ice lenses (95). However, such chemical treatment is probably

1. In unconfined compression
2. See page 12 for a description of the technology of excavating frozen soil.

too expensive to be used in mass earthwork. Therefore, such treatment was not considered in this study.

Tests reported by Hofmann (44,45) indicate that the compaction of soil is affected by temperature above about 32°F as shown in Figure 2. In general, the maximum unit weight is decreased and the optimum water content is increased with decrease in temperature, although the changes are minor. According to Hogentogler (46) these changes can be qualitatively explained by the increased viscosity of water at lower temperatures. However, compaction tests by the author disclosed that such temperature effects could not be detected in the compaction of two typical Indiana soils. The results of these tests are shown in Appendix C. Thus it is tentatively concluded that temperature does not significantly affect the compaction of Indiana soils, so long as the soil remains above about 32°F.

Cold Weather Effects on Machines

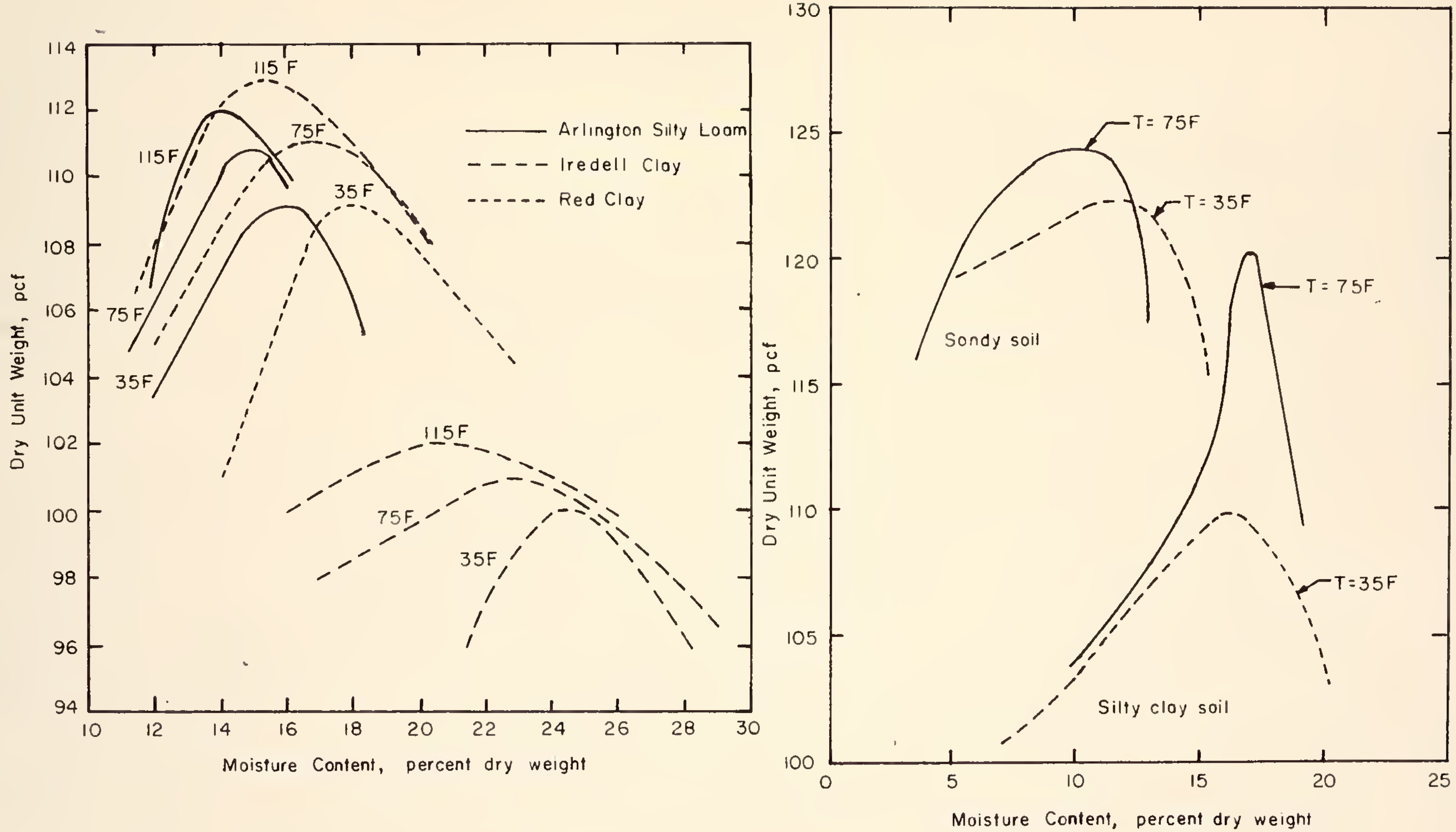
Cold weather conditions can effectively immobilize construction equipment of all types unless preventative maintenance is employed. The following is a brief outline of the preventative maintenance which may be required (22,67):

(1) Cooling system should be checked for leaks, equipped with proper thermostat, and filled with antifreeze solution.

(2) Fuel system:
   a. Use winter grade fuel.
   b. Check fuel lines often (every few days) for water.
   c. Drain water from fuel tank each evening.
   d. Fill fuel tank each evening to prevent condensation.

(3) Electrical system should be checked for loose connections and batteries should be checked and charged often.

(4) Manual clutches should be protected from rust due to condensation.



Std. AASHO Compactive Effort

Figure 2. Effect of Temperature on Compaction Characteristics (After 51)

(5) Glow plugs or ether starting devices should be installed on diesel engines.

(6) Crankcase oil of lower viscosity should be used.

(7) Tubes connected to the engine exhaust should be installed on the outside of truck and scraper bodies to prevent soil freezing to the body.

(8) Wire ropes should be throughly greased to prevent freezing to pulleys.

(9) Tracked equipment should be parked on timbers at night to prevent tracks freezing to the ground.

(10) Canvas hoods should be placed around engine compartments.

(11) Cabs should be installed for operator protection.

In very cold weather, say below - 20°F., more extensive effort is required to keep the equipment operational. In addition, metal embrittlement may become a significant consideration (20,87). However, these problems are not germane to winter work in Indiana (115).

In keeping with the thesis that earthwork capabilities may need to be maintained under almost any meteorological condition, the conclusions of a recent Swedish survey (6), relative to the operational efficiency of construction equipment with temperature (T), light (L) and precipitation (P), are presented in Table 2. Values of (E_T%), (E_L%), and (E_P%) from Table 2 can be combined in a model of the form:

$$\text{Net Relative Efficiency } E\% = (E_T\%)(E_L\%)(E_P\%) \div 10{,}000.$$

Table 2

Relative Efficiency of Operation of Construction Machinery (6)

Weather Factor	Excavation Machinery	Hauling Machinery
Air Temperature (°F):	E_T%	E_T%
85	87	89
70	99	100
50	100	100
40	99	100
32	99	97
25	98	100
15	92	96
- 5	78	88
- 25	43	66
Light Condition:	E_L%	E_L%
Bright Sunshine	96	96
Indirect Sunshine	100	100
Dusk	88	96
Subarctic Winter Twilight	65	82
Precipitation:	E_P%	E_P%
Heavy Rain	81	85
Light Rain	97	98
Dry, Temperature 50°F	100	100
Light Snow	97	95
Heavy Snow	73	76

PRESENT STATE OF COLD WEATHER EARTHWORK PRACTICE

Northern United States

To determine the present state of cold weather earthwork practice in the northern United States, questionnaires were sent to the state highway department soils engineers of each of the northern states deemed to have Winters at least as severe as Indiana. A sample questionnaire is included as Appendix A. The questionnaires were sent to twenty-one states, and all were completed and returned. Table 3 is a summary of the answers.

It is obvious that the cold weather earthwork practices of the different states vary tremendously. Some of this variation can be attributed to a difference in general soil types encountered. For example, most of the extensive wintertime earthwork in Michigan is done with its abundant sands (66). However, many of the variations in practices between states do not admit such a simple logical explanation. For example, several states allow contractors to place frozen soil as the outer shell of highway embankments. However, most states do not permit any frozen soil to be placed in any position in any highway embankment.

Excavation and Placement

It is now practical to excavate soil frozen to limited depths by ripping it in a grid pattern with large tracked or rubber-tired tractors, followed by loading into conventional rubber-tired scrapers. This

Table 3

Northern United States' Answers to Cold Weather Earthwork Questionnaire

State	Frozen Soil					Earthwork Season		Placing Fill, Air Temp. < 32°F					Additional Comments
	Excavation: Permitted (Encouraged)	Thickness Excavated	Methods of Excavation	Uses Permitted	Are Fills Satisfactory	Conditions Governing Working	Dates: From/To	Is This Permitted?	Can w% be Adjusted?	Methods Used to Place and Compact Fill	Is Fill Satisfactory?	Control Methods Used	
Colorado (57)[1]	no no	-	-	-	-	Frozen Soil	2-15 12-15	yes	-	-	-	-	
Idaho (48)	no no	-	-	-	-	Frozen Soil	4-15 11-1	yes	no	usual	yes	usual	Rock Work in Winter
Illinois (26)	yes yes	any	Ripper Scraper	Stockpile Waste	not used	Frozen Fill	5-1 12-1	yes	no	usual	yes	AASHO Nuclear	Limited Experience
Iowa (4)	yes no	2'-3'	Ripper Scraper	Waste	not used	Frozen Fill	4-15 12-1	yes	no	usual	yes	usual	

Table 3

Northern United States' Answers to Cold Weather Earthwork Questionnaire

State	Frozen Soil					Earthwork Season		Placing Fill, Air Temp. < 32°F					Additional Comments
	Excavation: Permitted (Encouraged)	Thickness Excavated	Methods of Excavation	Uses Permitted	Are Fills Satisfactory	Conditions Governing Working	Dates: From/To	Is This Permitted?	Can w% be Adjusted?	Methods Used to Place and Compact Fill	Is Fill Satisfactory?	Control Methods Used	
Colorado (57)[1]	no no	-	-	-	-	Frozen Soil	2-15 12-15	yes	-	-	-	-	
Idaho (48)	no no	-	-	-	-	Frozen Soil	4-15 11-1	yes	no	usual	yes	usual	Rock Work in Winter
Illinois (26)	yes yes	any	Ripper Scraper	Stockpile Waste	not used	Frozen Fill	5-1 12-1	yes	no	usual	yes	AASHO Nuclear	Limited Experience
Iowa (4)	yes no	2'-3'	Ripper Scraper	Waste	not used	Frozen Fill	4-15 12-1	yes	no	usual	yes	usual	
Kansas (47)	yes no	-	-	Waste	not used	-	3-1 12-30	yes	no	usual	yes	Sand Cone	
Maine (65)	yes no	to 1'	-	Waste	yes	Frozen Fill	4 12	yes	no	usual	yes	Sa Cone Nuclear	Low Fills on Frozen Soil
Michigan (66)	yes no	any	Ripper Scraper	Outer Fill	yes	Snow	5-1 11-15	yes	no	Ramp Method	yes	(2)	Sand Work all Winter
Minnesota (25)	no no	-	-	-	no	Frozen Soil	4-15 11-15	yes	no	usual	yes	Sand Cone	Limited (3") Frost in Fills
Missouri (74)	no no	-	-	-	-	Frozen Soil	4-1 11-1	yes	no	usual	yes	Sand Cone	No Frost or Snow in Fill
Montana (32)	yes no	-	-	Waste	-	Frozen Soil	4-1 11-1	-	-	-	-	-	Rock Work and Clearing
Nebraska (78)	yes no	to 6"	Ripper Scraper	Waste	-	Frozen Soil	3 12	yes	no	usual	yes	undis-turbed	Fill Freezing Permitted
New Hampshire (114)	yes no	-	Ripper Dozer	Berms	not used	Frozen Fill	3-15 12	yes	no	-	-	Sand Cone	Rock Work and Clearing
New York (45)	yes no	any	Ripper Shovel	Waste	no	Frozen Fill	4-1 11-15	yes	no	-	yes	Sand Cone	Rock Work in Winter
North Dakota (121)	no no	-	-	-	-	Frozen Soil	4-1 11-15	no	-	-	-	-	
Ohio (92)	yes no	-	-	Waste	not used	Frozen Fill	5-1 11-1	yes	no	usual	yes	Sand Cone	Limited Experience
Oregon (122)	yes no	to 6"	Scraper	Waste	no	Year Round	1-1 12-30	yes	yes	usual	yes	usual	
Pennsylvania (82)	no no	-	-	-	-	32°F Temp.	-	no	-	-	-	-	
South Dakota (68)	no no	-	-	-	-	32°F Temp.	3-15 12-1	yes	-	-	-	-	Work Heavy Cuts Till Jan.
Vermont (113)	yes no	-	Dozer	Waste	no	Frozen Fill	4-1 12-15	yes	no	usual	yes	Sa Cone Nuclear	Compaction Controls
Washington (85)	yes no	to 2"	Dozer	Fill	yes	Rain Snow	4-1 11-1	yes	no	usual	yes	ASTM D698	No Snow in Fill
Wisconsin (120)	yes no	-	-	Fill	no	Frozen Fill	-	yes	no	usual	yes	usual	
Wyoming (98)	yes no	-	Ripper	Waste	-	Frozen Fill	4-1 11-1	no	-	-	-	-	Rock Work in Winter

1. See Bibliography, page 70. 2. Volumeter

method is applicable to all types of soil. Rock excavation can also be carried out in cold weather using the same methods which are common in warm weather. In addition, peat excavation can be carried out with rippers and rubber-tired scrapers, or with dragline and trucks, more easily in cold weather because freezing improves access to the deposits (20).

Rock, peat, and dry sand and gravel which are excavated in cold weather can be placed in the same locations and with the same methods used in warm weather. However, the disposition of most excavated frozen soil is limited. Naturally, if excavation quantities exceed fill requirements frozen soil can be wasted; or frozen surface soil can be excavated and stockpiled for future warm weather spreading (26). If berms are a feature of the design section, frozen soil can perhaps be used to construct them. Moreover, frozen soil can be used in highway embankment sections if placed outside of a limiting slope line (usually 1:1) (66). Figure 3 illustrates the above-mentioned dispositions of frozen soil.

The reader will recognize that the uses of frozen soil correspond to those of inferior materials encountered in normal working season construction. For example, the standard plan for treatment of peat marshes of the State of Michigan (64) shows similar uses.

Research defining stresses in and beneath embankment sections will ultimately permit a more rational judgment as to permissive locations of material of low strength. Such research is presently under way at Purdue University...Perloff et al. (83). For example, Figure 4 shows the distribution of maximum shearing stresses within and beneath a given embankment of height (H) width (2L) and slope angle (α). The soil mass has a unit weight (γ) and is assumed to be homogenous, isotropic and

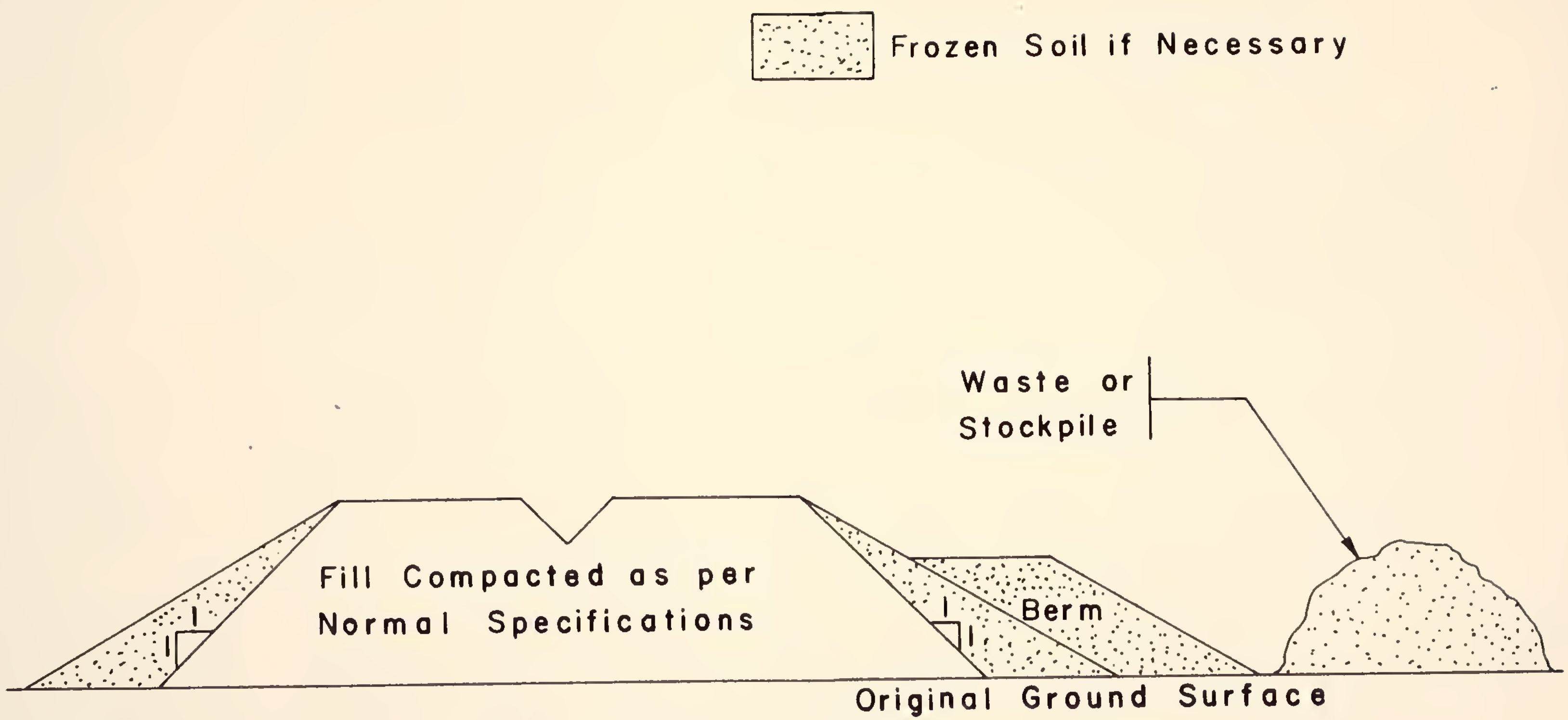


Figure 3. Locations Where Frozen Soil Can Be Used Without Detrimental Effects

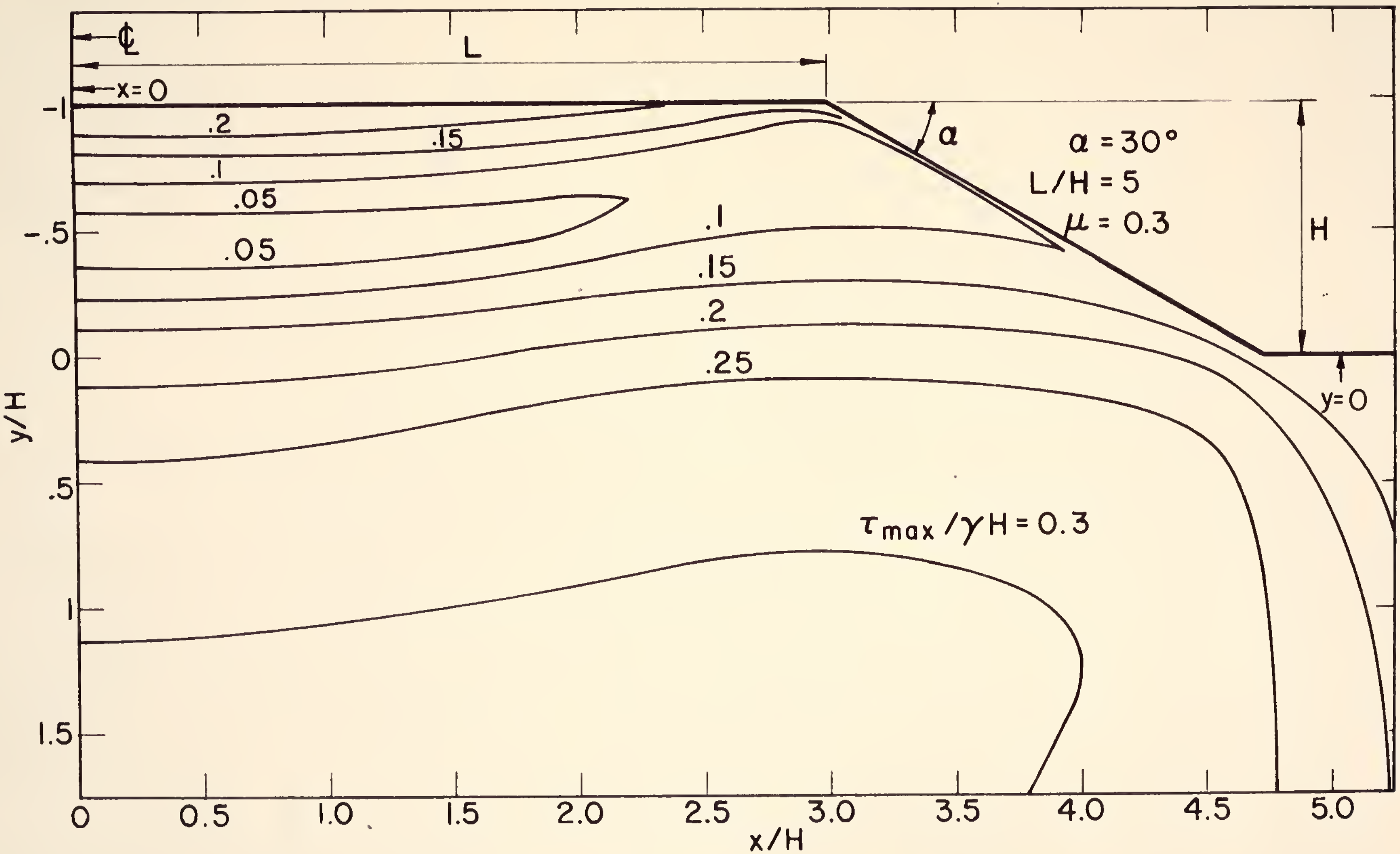


Figure 4 - Contours for Maximum Shear, $\tau_{max}/\gamma H$

(Courtesy of Baladi and Perloff, Purdue University)

lineally elastic (Poisson's ratio...μ). While the assumed model is not strictly applicable, such results provide valuable insight with respect to the real problem, and are a significant improvement over any previous solution.

After frozen soil is removed from the borrow area, the underlying unfrozen soil can be excavated by normal means. If the air temperature is much below freezing, the active borrow area should be kept small (72). Likewise the uncompacted fill area should be kept small to avoid freezing before complete compaction. One method of minimizing exposed surface is the ramp placement technique (66). As shown in Figure 5, this method consists of advancing the embankment by placing the fill on as steep a slope as is practicable.[1] This procedure limits freezing of the embankment to the finished grade, where freezing is permissible if paving is to be delayed until warm weather. Also, this procedure minimizes the area of the layer which will freeze overnight or over a weekend and which might then have to be removed before fill placement could proceed (93).

Compaction

One agency (61) states that in cold weather compaction, the water content of the soil must be within 2% of the optimum for compaction. If the temperature is above freezing, and will remain so, the water content can be raised to this requirement by normal watering. However, if the natural water content is too high the only practical means of lowering it is to mix the too-wet soil with soil which has a lower water content. Drying on the grade is not practical because of lowered evaporation rates, plus uncertainties about the ambient temperatures and precipitation.

1. Note that compaction planes are inclined.

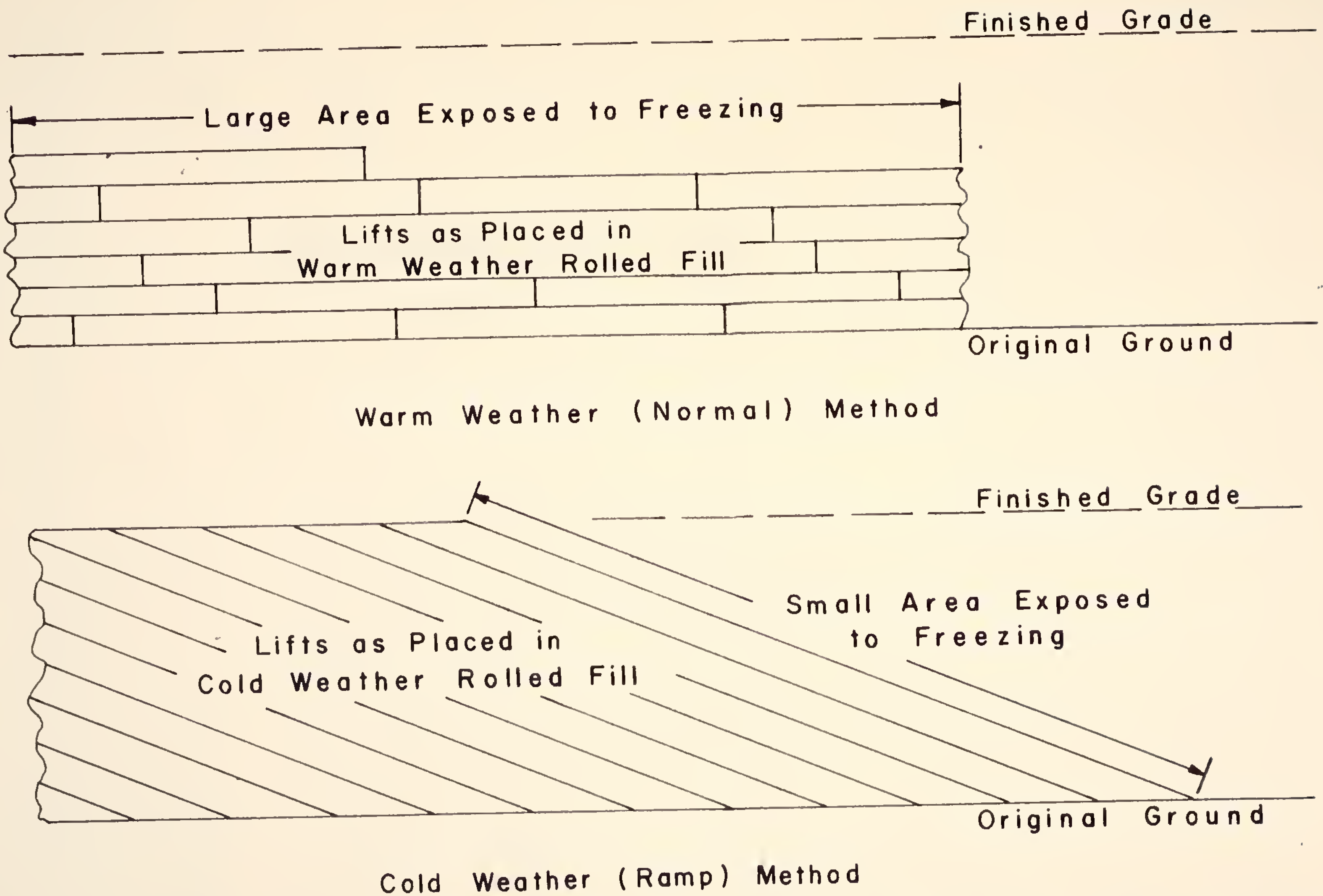


Figure 5. Embankment Profiles, Warm Weather vs. Cold Weather Lifts in Rolled Fills

Other methods such as drying soil in asphalt pug mills have been used (67) but are too expensive for normal consideration.

Compaction control can be exercised by normal methods so long as the soil is unfrozen.[1] If for any reason it is desired to check the density of a lift which is already frozen, the best method is to cut a block sample for direct volume and weight determination. It is apparently not feasible to use nuclear techniques for frozen soils (105).

Figure 6 summarizes principal features of current U. S. practice by showing the percentage of northern states presently using the cold weather earthwork techniques discussed.

Contractors in Indiana

After determining the cold weather earthwork practices in use in the northern states it was decided to determine the specific experiences of contractors operating in Indiana. A list of 22 contractors doing heavy earthwork in Indiana was obtained from the Indiana State Highway Department. The contractors were asked the questions shown in Appendix B. Nineteen of them responded. Their answers are tabulated as Table 4. It can be seen that more than half of these contractors have some experience in excavating frozen soil and a few of them have experience in placing frozen soil. Figure 7 summarizes the experience with respect to various earthwork operations in cold weather.

Several of the contractors indicated that their operating expenses for cold weather increased greatly (Table 4). This tremendous increase may be very much a function of limited experience, and hence treatment

1. It may be necessary to add anti-freeze to the water in certain of the compaction checking devices.

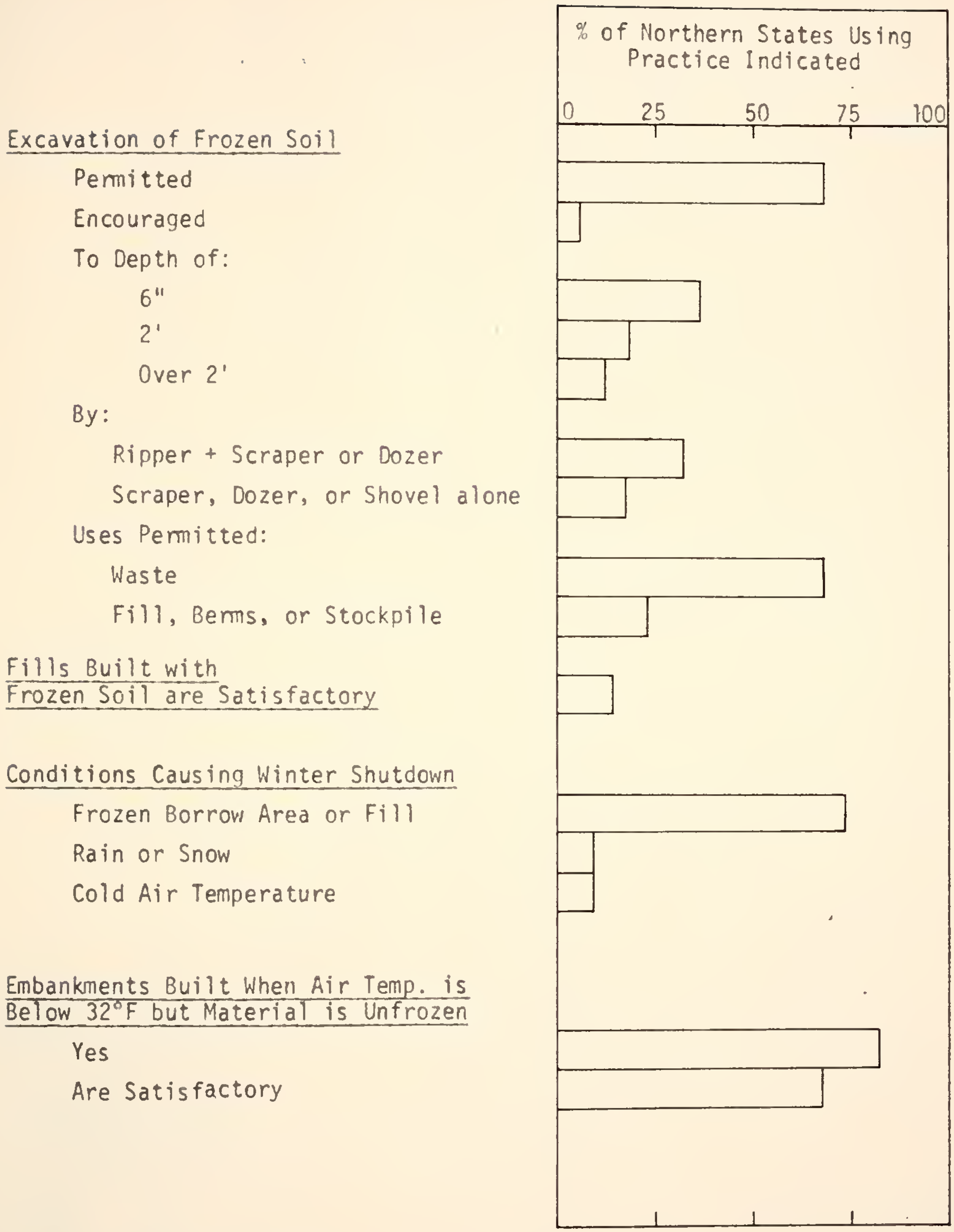


Figure 6. State of Winter Earthwork in the Northern U. S.

Table 4

Contractors' Replies to Cold Weather Earthwork Questionnaire

* Indicates work done outside Indiana

Contractor	Have you excavated frozen ground?	Thickness which you excavated	Methods Used	Were methods successful?	Uses of Excavated frozen soil	Did it perform satisfactorily?	Usual Conditions causing fall shutdown	Usual Conditions permitting spring start-up	Economic factors preventing your doing earthwork in winter	Have you kept records of winter costs?	What incentives would cause you to do earthwork all Winter?
[illegible]									Government Specs		

Table 4

Contractors' Replies to Cold Weather Earthwork Questionnaire

* Indicates work done outside Indiana

Contractor	Have you excavated frozen ground?	Thickness which you excavated	Methods Used	Were methods successful?	Uses of Excavated frozen soil	Did it perform satisfactorily?	Usual Conditions causing fall shutdown	Usual Conditions permitting spring start-up	Economic factors preventing your doing earthwork in winter	Have you kept records of winter costs?	What incentives would cause you to do earthwork all Winter?
Berns Const. Co. (12)[1]	very little	12"	Large Ripper	Fair	Waste	yes	Frozen Ground	Drying Soil	Government Specs against frozen soil in fills	no	More pay Change Specs.
Contracting & Material Co. (53)	yes	13"	Ripper Scraper	yes	Fill	yes	Water Soil Econ.	Water Soil Econ.	Cold Operators Equip. Breakage Extra Grading	yes	More pay
Calumet Paving Co. (18)	yes	12" to 14"	Ripper	yes	Fill	yes	Frozen Ground	Thawing Soil	Cost of Ripping Equipment Breakage	yes	More pay
Engineering Const. Co. (27)	yes	36"	D8 with Ripper	yes	Waste (Peat)	yes	Wet Soil	Drying Soil	-	no	Granular Material
Jay Fox Const. Inc. (23)	very little	18"	D8 with Ripper	yes	Waste	yes	Wet or Frozen Soil	Weather	Lost time Equip. Breakage	yes	Dry Weather
Green Const. of Indiana, Inc. (36)	yes	2" to 36"	Ripper Blasting	yes	Waste	yes	Frozen Soil	Drying Soil	Rain and Cold	yes + 300%	Rush Job
S. J. Groves and Sons Co. (38)	no	-	-	-	-	-	-	-	-	-	-
L.H. Gunsaullis (39) and Son, Inc.	no	-	-	-	-	-	Frozen Soil	Thawing Soil	Prohibitive Cost	-	"Cost plus" Job
Holloway Const. Co. (14)	yes	24"	D9 with Ripper	very	Fill outside 1:1 line	yes	Cold & Water	Drying Soil	Specifications Difficult Compaction	no	Dry Winter More pay
Peter Kiewit Sons Co. (34)	yes	*4' to 6'	Drill and Blast	yes	Waste	yes	Frozen Soil	Thawing Soil	High Cost (of operation)	no	More pay
McMahan Const. Co. (13)	very little	-	-	-	Waste (peat)	-	Frozen Soil	-	Cost of Handling Frozen Soil	no	-
Miller Brothers, Inc. (73)	little	0" to 12"	D8, D9, Ripper Scraper	yes	Waste	yes	Wet or Frozen Soil	Drying Soil	Cold Operators Handling Frozen Soil	no	Use of Wet & Frozen Soil in Fills
Ralph Myers Contracting Corp. (86)	no	-	-	-	-	-	Wet or Frozen Soil	Weather	-	no	Rock Excavation
J. C. O'Connor and Sons, Inc. (80)	some	12" to 36"	Dragline	yes	Waste (peat)	yes	Frozen Soil	Thawing Drying Soil	Specifications High Cost	yes + 100%	Keep Men Working
Olinger Const. Co. (81)	yes lots	to 18"	Ripper Blasting	yes	Fills	yes	Wet Soil	Drying Soil	High Maintenance Cold Operators	no	More pay Compactible Soil
Rock Road Const. Co. (88)	yes	24"	Shovel Ripper Scraper	good good fair	Waste	yes	Wet or Frozen Soil	Thawing Drying Soil	High Operating Costs	yes + 100%	More pay Compactible Soil
Spears-Dehner, Inc. (97)	yes	12"	Ripper	yes	Waste Peat Excav.	yes	Wet Soil	Drying Soil	High Maintenance Low Efficiency	no	Peat Replacement Job
Stone City Const. Co. (99)	yes	24"	Ripper Shovel	yes yes	Waste Stockpile	yes yes	Frozen Soil	Drying Soil	Low Efficiency	no + 30%	More pay Rush Job
Tri-Angle Const. Co., Inc. (106)	yes	12"	Ripper Blasting	yes fair	Waste Fill	yes yes	Wet or Frozen Soil	Drying Soil	Low Production Low Efficiency	no + 40%	Rush Job Dry Winter

1. See the Bibliography, page 70.

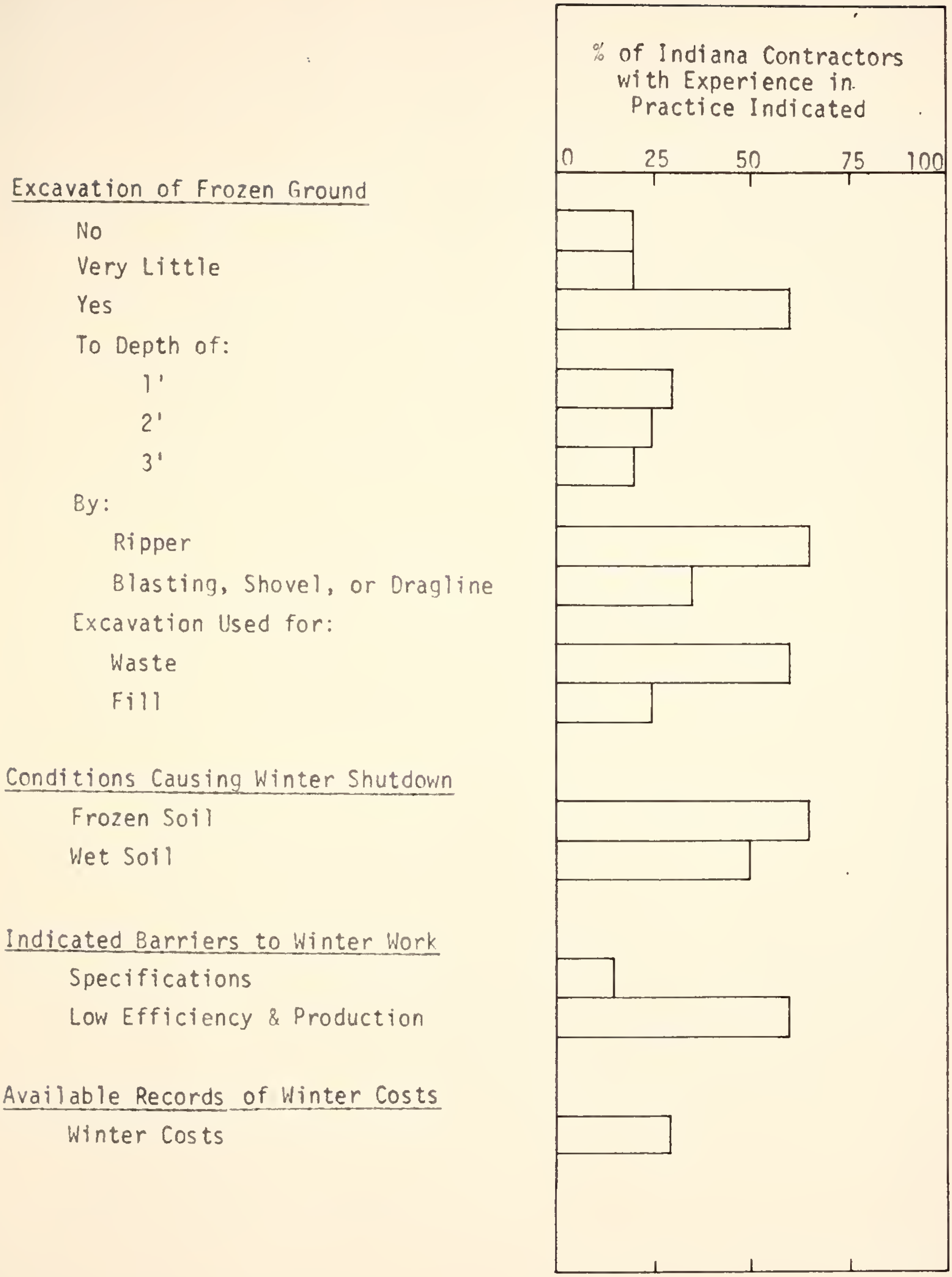


Figure 7. Contractors' Winter Experience in Indiana

of the activity as a highly unusual one. Some of the respondents may have feared that cold weather work was being studied with the premise that normal specifications and rates of reimbursement would apply. Such is not the author's perspective. It is disappointing that the respondents did not stress the potential benefits of fuller utilization of equipment and working forces, although the questions posed did not directly address this point. On the positive side, it is important that Indiana contractors do have some experience with cold weather earthwork. Also, it will become apparent in the following sections that increased unit costs do not necessarily mean that cold weather earthwork is uneconomical.

Canadian Provinces and Alaska

To determine the present state of cold weather earthwork practice in Canada and Alaska, questionnaires were sent to the highway department soils engineers of each of the Canadian Provinces and of Alaska. This questionnaire was identical to the one in Appendix A, except that the engineers were asked specifically to omit permafrost considerations in responding. Table 5 summarizes the answers.

A few practices were mentioned which were over and above those of the northern states. The most impressive is the practice (105) of building highway embankments of alternate lifts of frozen cohesive soil and frozen granular soil.[1] These embankments are compacted as well as practicable, but are allowed to thaw and settle in the spring and summer before paving.

Another Canadian practice (103) is to raise embankments to within 5 feet of the finished grade in cold weather, and then finish them in the

1. This is analogous to the use of alternate dry and too-wet lifts in warm weather construction (37).

Table 5

Canadian and Alaskan Answers to Cold Weather Earthwork Questionnaire

Province, State, or Company	Frozen Soil					Earthwork Season		Placing Fill, Air Temp. < 32° F					Additional Comments
	Excavation: Permitted (Encouraged)	Thickness Excavated	Methods of Excavation	Uses Permitted	Are Fills Satisfactory	Conditions Governing Working	Dates: From/To	Is This Permitted?	Can w% be Adjusted?	Methods Used to Place and Compact Fill	Is Fill Satisfactory?	Control Methods Used	
Alaska (2)[1]	yes yes	to 15'	Ripper	Fill if granular	yes	Cold Snow	4-1 10-1	yes	no	usual	yes	Sa Cone (3)	EM 1110-1-306 Specs. used
Alberta (3)	no no	-	-	-	-	Frozen Fill	4-15 11-1	yes	no	usual	yes	visual	Operate 24 Hrs./Day
British Columbia (87)	yes no	any	D9 Ripper	Access Roads	yes	Very Cold	6-15 11-1	yes	no	usual	yes	no answer	Stockpile Gvl. in Winter
Manitoba (20)	yes no	to 8'	Ripper Scraper	Swamp Fills	yes	Rain Cold	5-1 11-1	yes	no	usual	yes	Sand Cone	
New Brunswick (103)	yes no	2'	Ripper	Fill Waste	yes	Judge-ment	5-20 12-20	yes	no	usual	yes	Sa Cone (3)	Place Sa & Gvl. in Winter
Newfoundland (96)	no no	-	-	-	-	Frozen Fill	5-1 12-1	rare yes	no	1'-2' Lifts	yes	none	Winter fills settle
Nova Scotia (35)	yes no	to 3'	D9 Ripper	Access Roads	no	6" of Frost	5-1 12-1	yes	yes	usual	yes	Sand Cone	Rip Frost off Borrow Pit
Ontario (104)	yes no	2'-3'	Shovel Trucks	Waste	no	Frozen Fill	4-15 12-1	yes	no	usual	yes	Sand Cone	Normal Specs. Must be Met
Quebec (105)	yes yes	any	Shovel	Fill if Granular	yes	Specs.	5-15 12-1	yes	no	vibrate	yes	Dens-o-meter	Do Rock Work in Winter
Saskatchewan (72)	yes no	1'	D8 Ripper	Fill if Granular	yes	Cold Snow	5-1 12-1	yes	no	usual	yes	none	Operate 24 Hrs./Day
Yukon Territory (54)	yes no	3'	D7 - D9 Ripper	Fill if Granular	yes	Very Cold	4-15 11-15	yes	no	vibrate	yes	none	Much Work in Cold
Terratech[2] Ltee (90)	yes yes	3'-4'	Ripper Shovel	Waste	yes	20°F	5-15 12-1	yes	no	usual	yes	Sand Cone	

1. See Bibliography 70. 2. Canadian Contractor, Home Office in Montreal, Quebec. 3. Volumeter

early summer. Also, in some provinces (3,54,72), borrow areas are worked continuously (24 hours a day) once opened in freezing weather. Some provinces (3, 20) find cold weather the best time to build access roads in swampy areas because of excellent mobility of construction equipment on the frozen ground.

Figure 8 shows the percentage of Canadian and Alaskan Agencies presently using the cold weather earthwork practices discussed in this and the previous section.

Mr. Erwin L. Long (61), of the U. S. Army Corps of Engineers, Alaska District, made the following suggestions based on his experience with cold weather earthwork.

1. Stockpile clean sands, gravels, and gravelly sands to permit drainage and evaporation or sublimation of excess moisture from the particle surfaces as long as practicable prior to use. (Borrow may be either thawed or frozen).
2. If material has sufficient moisture to be in aggregated chunk form, compaction may be increased by encouraging the use of vibratory steel rollers and grid rollers to break down the aggregations and reduce the size of interparticle voids. In this case, the borrow material must have a moisture content below the warm weather optimum moisture content for maximum density.

Southeastern United States

The advantages accruing to contractors in the southeastern United States, who are able to work almost all year round, were determined by inquiries directed to 10 firms in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Mississippi. These contractors were asked to outline the nature of their cold season earthwork activities and to cite the advantages of year-round use of staff, labor, and machines.

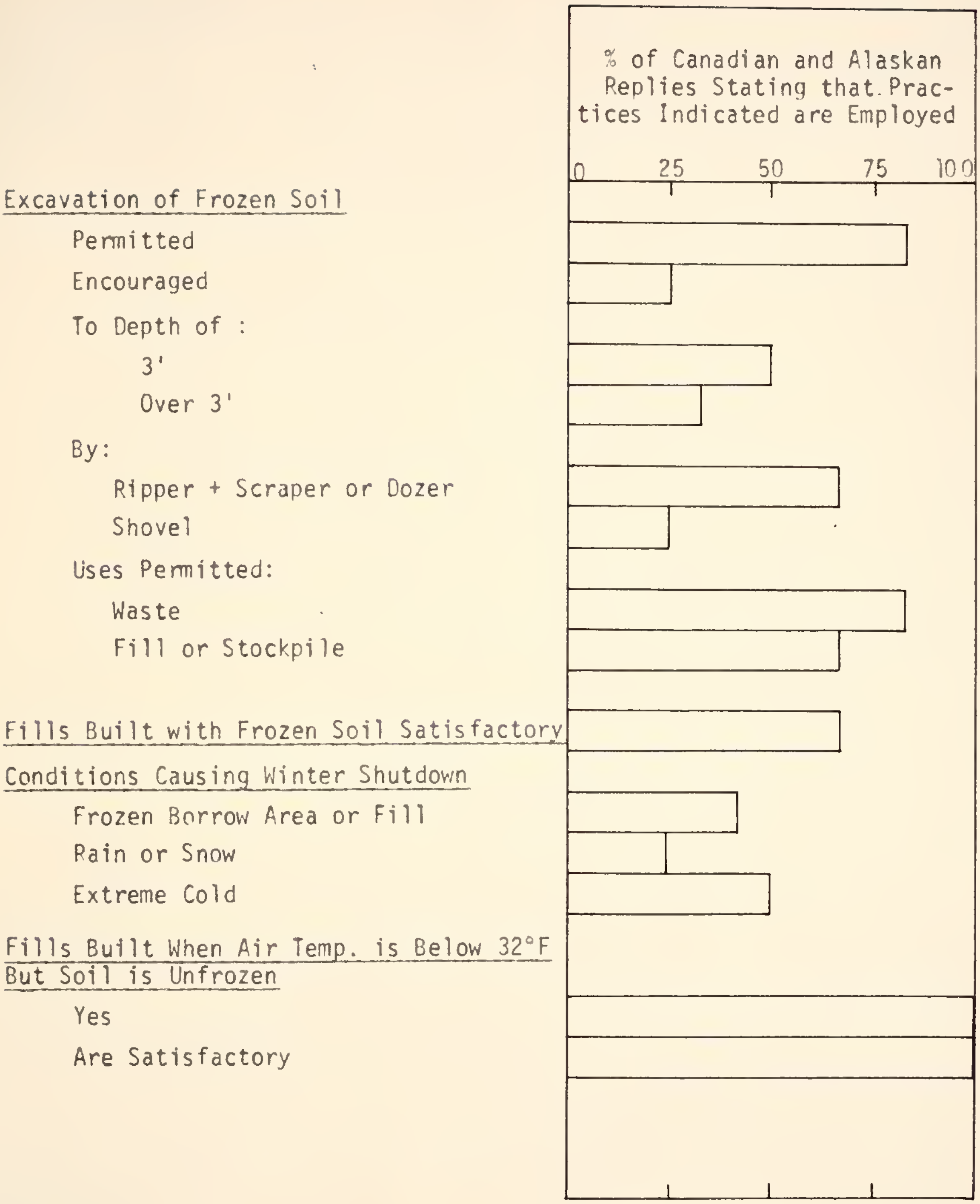


Figure 8. State of Winter Earthwork Practice in Canada and Alaska

Although most of these contractors suspend placing of fill for some period due to heavy winter rains, almost all felt it was definitely to their advantage to maintain a year-round construction operation.

Advantages cited in the responses were:

(1) 70% noted benefits of more full and effective use of their staffs;

(2) 70% pointed out improved relationships with skilled workers kept constantly in their employ;

(3) 70% preferred 12-month amortization of their expensive equipment;

(4) 30% were emphatic in the substantial benefit of year around utilization of machinery and operators;

(5) 30% stated that the elimination of shut-down and start-up expenses was of considerable help;

(6) 20% pointed out that as less elapsed calendar time was required to complete a job, more jobs could be undertaken.

All told, 8 out of the 10 southern contractors concluded that there is definite economic advantage in a year-round earthwork operation.

Scandinavian Countries

After determining the current cold weather earthwork practices in North America, further information from other parts of the world was solicited from the Norwegian Road Research Laboratory (29), the National Swedish Institute for Building Research (52), and the Associated General Contractors and Home Builders of Sweden (6). These responses were very helpful and informative. In particular, the Productivity Council of the Associated General Contractors and House Builders of Sweden (hereafter called SBEF, a Swedish abbreviation) contributed a 187-page report entitled "Eliminating Seasonal Variations in Road Construction," which is the result of an extensive study made by SBEF into year-round road construction in Sweden.

The conclusions of the SBEF report are based on an intensive opinion survey of experienced road builders. In all, 13 men were interviewed; 11 contractors and 2 Royal Highway officials. Each of these men answered 6,500 individual questions relative to the variation of road building costs with the seasons. The SBEF then compiled this input for individual operations in each of four climatic zones in Sweden. These zones correspond in snowfall and temperatures to the areas in the United States shown in Figure 9. Table 6 shows the relative cost predictions of the SBEF study. The control cost in each case is for summer operation.

Although the accumulated experiences were from different climatic zones a definition of four technical earthwork seasons made possible a valid grouping of the responses. The definitions are as follows. "Summer" starts when the water content of soil begins to decrease due to evaporation exceeding precipitation.[1] "Fall" begins when the air temperatures becomes so low that the soil no longer dries rapidly by evaporation. "Winter" begins when the ground no longer thaws between cold periods but stays frozen. "Spring" starts when the snow no longer completely covers the ground. Opinions of the experienced engineers relative to the advisability of undertaking certain operations during the various earthwork seasons are summarized in Table 7.

When excavating in frozen soil it may be more economical to insulate the ground against freezing by artificial means such as spreading a dry mixture of sand and sawdust over the area to be protected at the end of the workday. Table 8 compares the increased cost of excavation using the two methods.

1. Input of this type is available for the U. S. See Thornthwaite(101) for example.

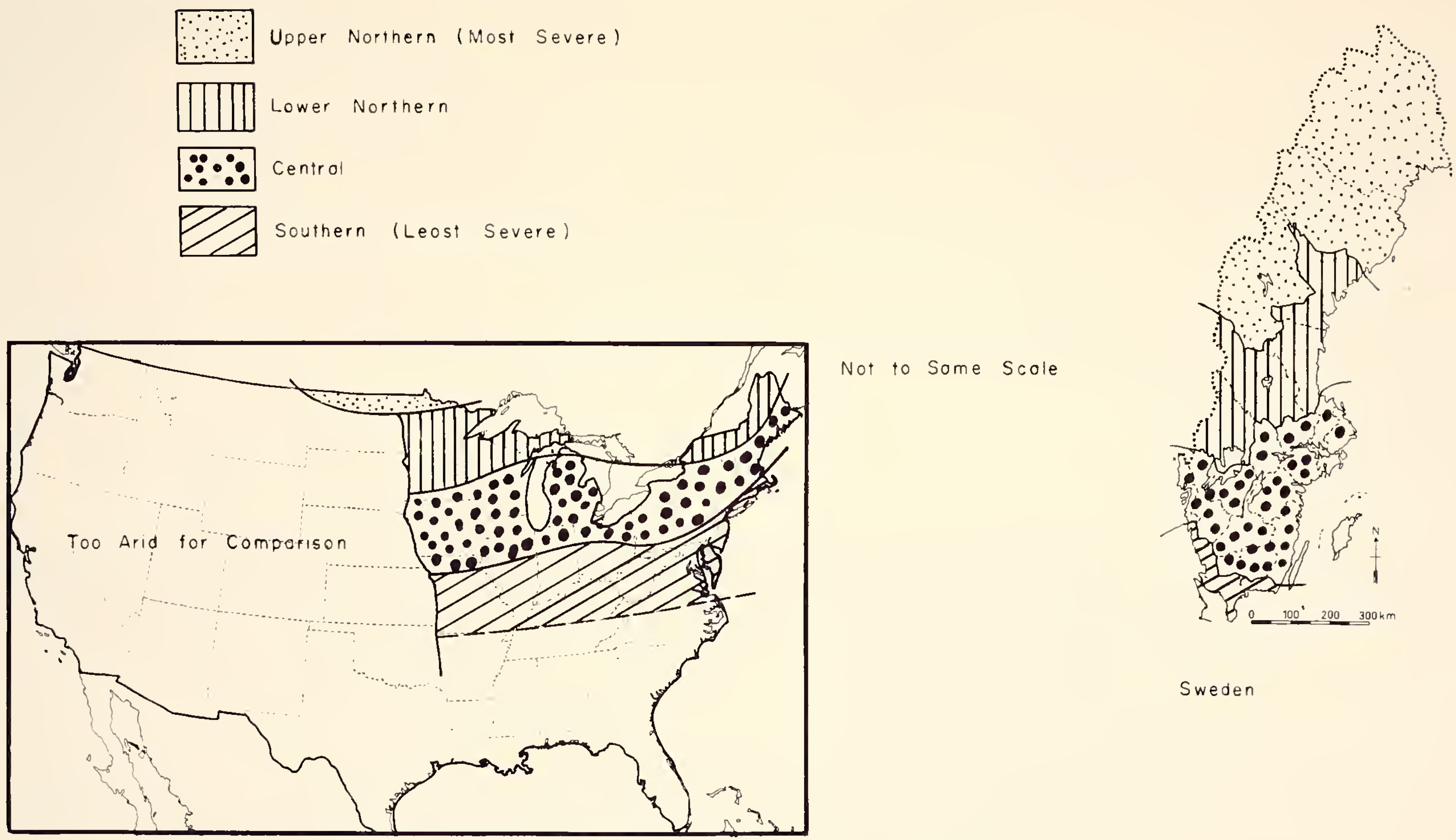


Figure 9. Areas of Sweden and the United States Having Similar Climates

Table 6

Relative Cost of Construction Operations in Different Seasons in Different Areas (After 6)

Class of Operation Work Items H = Depth of Excavation L = Length of Haul V = Excavation Volume/Cut	Relative Cost															
	Southern Sweden				Central Sweden				Lower Northern Sweden				Upper Northern Sweden			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
Setting up Plant	100	105	111	102	100	105	111	102	100	105	133	114	100	105	133	114
Clearing:																
Trees & Branches	100	100	100	105	100	100	116	100	100	100	157	105	100	100	157	105
Stumps & Brush	100	110	180	143	100	110	180	143	100	110	180	143	100	110	180	143
Stripping Topsoil	100	140	180	155	100	140	204	155	100	130	204	170	100	130	204	170
EXCAVATION																
Sand & Gravel																
H = 18", V = 500 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	101	135	113	100	101	179	113	100	110	179	134	100	110	179	134
Scraper (L=1000')	100	101	162	125	100	101	172	125	100	115	-	158	100	115	-	158
Shovel (L over 3/4 mile)	100	102	167	115	100	102	167	115	100	105	153	129	100	105	153	129
(b) Cutting to Grade	100	106	160	130	100	106	160	130	100	107	162	126	100	107	162	126
H = 8', V - 5000 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	101	130	108	100	101	150	108	100	108	150	120	100	108	150	120
Scraper (L=1000')	100	101	133	123	100	101	133	123	100	113	206	147	100	113	206	147
Shovel (L>3/4 mi)	100	103	113	108	100	103	113	108	100	105	121	113	100	105	121	113
(b) Cutting to Grade	100	105	148	124	100	105	148	124	100	106	148	115	100	106	148	115

Table 6 (cont'd.)

Class of Operation Work Items H = Depth of Excavation L = Length of Haul V = Excavation Volume/Cut	Relative Cost															
	Southern Sweden				Central Sweden				Lower Northern Sweden				Upper Northern Sweden			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
Moraine																
H = 18", V = 500 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	109	145	128	100	109	185	128	100	117	185	148	100	117	185	148
Scraper (L=1000')	100	110	168	145	100	110	168	145	100	115	-	163	100	115	-	163
Shovel (L>3/4 mi)	100	111	169	130	100	111	169	130	100	108	169	143	100	108	169	143
(b) Cutting to Grade	100	113	176	140	100	113	176	140	100	111	176	143	100	111	176	143
H = 8', V = 5000 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	108	135	110	100	108	158	110	100	113	158	125	100	113	158	125
Scraper (L=1000')	100	109	142	139	100	109	142	139	100	113	210	150	100	113	210	150
Shovel (L>3/4 mi)	100	110	114	113	100	110	114	113	100	108	129	117	100	108	129	117
(b) Cutting to Grade	100	111	163	140	100	111	163	140	100	109	164	134	100	109	164	134
Quicksand[1]																
H = 18", V = 500 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	156	189	165	100	156	209	165	100	127	209	157	100	127	209	157
Scraper (L=1000')	100	214	210	271	100	214	210	271	100	121	-	167	100	121	-	167
Shovel (L>3/4 mi)	100	141	174	184	100	141	174	184	100	123	185	167	100	123	185	167
(b) Cutting to Grade	100	152	182	170	100	152	182	170	100	116	182	159	100	116	182	159

1. Saturated fine sand and silt.

Table 6 (cont'd.)

Class of Operation Work Items H = Depth of Excavation L = Length of Haul V = Excavation Volume/Cut	Relative Cost															
	Southern Sweden				Central Sweden				Lower Northern Sweden				Upper Northern Sweden			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
H = 8', V = 5000 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	153	176	167	100	153	160	167	100	121	160	137	100	121	160	137
Scraper (L=1000')	100	175	159	197	100	175	159	197	100	118	219	152	100	118	219	152
Shovel (L>3/4 mi)	100	133	117	145	100	133	117	145	100	118	134	140	100	118	134	140
(b) Cutting to Grade	100	152	175	163	100	152	175	163	100	112	175	154	100	112	175	154
Clay																
H = 18", V = 500 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	141	188	147	100	141	214	147	100	149	214	197	100	149	214	197
Scraper (L=1000')	100	173	222	206	100	173	222	206	100	151	-	195	100	151	-	195
Shovel (L>3/4 mi)	100	146	163	158	100	146	163	158	100	125	190	173	100	125	190	173
(b) Cutting to Grade	100	143	183	161	100	143	183	161	100	116	182	159	100	116	182	159
H = 8', V = 5000 yd.^{3}																
(a) Excavating with:																
Bulldozer (L=150')	100	141	175	150	100	141	144	150	100	142	144	171	100	142	144	171
Scraper (L=1000')	100	158	158	181	100	158	158	181	100	147	206	175	100	147	206	175
Shovel (L>3/4 mi)	100	131	117	135	100	131	117	135	100	115	123	151	100	115	123	151
(b) Cutting to Grade	100	140	174	161	100	140	174	161	100	109	172	146	100	109	172	146
Rock Blasting:																
H = 0-3'	100	100	105	102	100	100	105	102	100	102	114	106	100	102	114	106
H = over 3'	100	101	102	102	100	101	102	102	100	101	109	103	100	101	109	103

Table 6 (cont'd.)

Class of Operation Work Items H = Depth of Excavation L = Length of Haul V = Excavation Volume/Cut	Relative Cost															
	Southern Sweden				Central Sweden				Lower Northern Sweden				Upper Northern Sweden			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
BUILDING FILLS																
Sand & Gravel																
(a) Dumping Fill from:																
Scrapers	100	101	126	123	100	101	126	123	100	113	168	138	100	113	168	138
Bottom Dumps (L = 1 1/2 mi.)	100	103	108	107	100	103	108	107	100	104	112	110	100	104	112	110
(b) Spreading & Compacting	100	105	150	126	100	105	150	126	100	105	148	119	100	105	148	119
Moraine																
(a) Dumping Fill from:																
Scrapers	100	108	133	138	100	108	133	138	100	107	160	136	100	107	160	136
Bottom Dumps (L = 1 1/2 mi.)	100	109	111	114	100	109	111	114	100	107	116	114	100	107	116	114
(b) Spreading & Compacting	100	110	162	140	100	110	162	140	100	108	160	133	100	108	160	133
LEVEE CONSTRUCTION	100	110	174	132	100	110	174	132	100	110	174	132	100	110	174	132
EXCAVATION (FOR WASTE)																
(a) Digging:																
Without Hauling	100	120	94	141	100	120	94	141	100	120	94	141	100	120	94	141
With Hauling Away (L = 1/2 mi.)	100	129	94	150	100	129	94	150	100	130	94	151	100	130	94	151
(b) Spreading (No Compaction)	100	160	139	173	100	160	139	173	100	129	115	203	100	129	115	203

Table 6 (cont'd.)

Class of Operation Work Items H = Depth of Excavation L = Length of Haul V = Excavation Volume/Cut	Relative Cost															
	Southern Sweden				Central Sweden				Lower Northern Sweden				Upper Northern Sweden			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
	1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	3C	3D	4A	4B	4C	4D
PLACING CULVERTS:																
Diameter = 60"	100	109	110	136	100	109	110	136	100	109	110	136	100	109	110	136
Diameter = 24"	100	111	111	141	100	111	111	141	100	111	111	141	100	111	111	141
PLACING 9" CONCRETE PIPE	100	114	117	132	100	114	117	132	100	114	117	132	100	114	117	132
PLACING SUB BASE (L = 3 mi.)	100	101	100	104	100	101	102	106	100	101	107	109	100	101	103	107
PLACING BASE COURSES																
Gravel (L = 3 mi.)																
Crushing	100	100	109	100	100	100	109	102	100	103	111	106	100	103	111	106
Spreading & Compacting	100	101	114	106	100	101	115	108	100	101	120	109	100	101	120	109
Macadam (L = 3 mi.)																
Blasting	100	100	102	100	100	100	102	100	100	102	111	102	100	102	111	102
Crushing	100	100	105	100	100	100	105	100	100	100	105	100	100	103	109	103
Spreading & Compacting	100	101	110	108	100	102	117	111	100	102	119	110	100	102	112	110
SPREADING TOPSOIL	100	117	181	141	100	117	181	141	100	117	-	141	100	117	-	-
BRIDGE, SPAN 15'	100	102	110	102	100	102	120	104	100	108	114	106	100	108	114	106
Placing 6" water lines or 15" sewer lines	100	107	116	102	100	119	116	115	100	119	116	115	100	119	116	115

Table 7

Answers to Questions Concerning Performing Certain Construction Operations in Different Seasons (After 6)

Answers to questions as to whether different working details are Advisable (A), or Possible but not advisable (P), from a Technical (T) point of view (with regard to quality) and from an Economic (E) point of view, in different seasons.

Operation Group of Working Items H = Depth of Excavation 1.0 = 100% of Experts Answering "Yes"	Summer				Fall				Winter				Spring			
	T		E		T		E		T		E		T		E	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Group I Mass Earthwork																
Clearing and Grubbing	0.9	0.1	0.8	0.2	0.9	0.1	0.8	0.2	0.6	0.2	0.4	0.4	0.7	0.2	0.6	0.4
Excavation																
Grading and Compacting																
Gravel and Sand	1.0	-	1.0	-	0.8	0.2	0.8	0.2	0.2	0.3	-	0.3	0.4	0.3	0.3	0.5
Moraine	1.0	-	1.0	-	0.5	0.5	0.5	0.5	0.1	0.3	-	0.2	0.3	0.3	0.2	0.4
Quicksand[1]	1.0	-	1.0	-	0.3	0.3	0.1	0.4	0.1	0.2	-	0.2	0.1	0.3	0.2	0.2
Clay	1.0	-	1.0	-	0.3	0.4	0.1	0.5	0.1	0.2	-	0.1	0.1	0.3	0.2	0.2
Excavating, Hauling, and Dumping																
Gravel and Sand H = 18"			1.0				0.8	0.2			-	0.4			0.4	0.4
	1.0	-		-	0.3	0.3			0.1	0.7			0.4	0.5		
H = 8'-16'			1.0				0.9	0.1			0.5	0.5			0.5	0.4
Moraine H = 18"			1.0	-			0.7	0.3			0.1	0.1			0.3	0.5
	1.0	-			0.4	0.6			0.1	0.8			0.3	0.7		
H = 8'-16'			1.0	-			0.6	0.4			0.3	0.6			0.3	0.5
Quicksand H = 18"			1.0	-			0.2	0.2			-	0.2			0.1	0.3
	1.0	-			0.3	0.3			0.2	0.7			0.2	0.3		
H = 8'-16'			1.0	-			0.2	0.3			0.2	0.5			0.1	0.4
Clay H = 18"			1.0	-			0.2	0.3				0.2			0.1	0.3
	1.0	-			0.3	0.5			0.2	0.7			0.1	0.5		
H = 8'-16'			1.0	-			0.2	0.4			0.2	0.5			0.1	0.4

1. Saturated fine sand and silt.

Table 7 (cont'd.)

Operation Group of Working Items H = Depth of Excavation 1.0 = 100% of Experts Answering "Yes"	Summer				Fall				Winter				Spring			
	T		E		T		E		T		E		T		E	
	A	P	A	P	A	P	A	P	A	P	A	P	A	P	A	P
Group I, Mass Earthwork, cont'd.																
Rock Blasting	1.0	-	1.0	-	1.0	-	1.0	-	0.9	0.1	0.8	0.2	0.9	0.1	0.9	0.1
Ditching	1.0	-	1.0	-	0.7	0.3	0.5	0.5	0.1	0.8	-	0.5	0.2	0.4	0.2	0.3
Excavation for waste	0.8	0.2	0.8	0.2	0.5	0.3	0.3	0.3	1.0	-	0.9	0.1	0.3	0.4	0.1	0.5
Group II Drainage Work																
Large Culverts	0.9	0.1	0.9	0.1	0.3	0.7	0.4	0.5	0.5	0.5	0.5	0.5	0.2	0.4	0.1	0.4
Small Culverts	1.0	-	1.0	-	0.5	0.5	0.4	0.6	0.3	0.6	0.3	0.7	0.2	0.4	0.1	0.4
Pipes	1.0	-	1.0	-	0.3	0.7	0.3	0.6	0.3	0.7	0.3	0.7	0.3	0.4	0.1	0.5
Group III Top Cover Work																
Sub-bases	1.0	-	1.0	-	0.6	0.3	0.6	0.4	0.6	0.2	0.5	0.5	0.2	0.4	0.2	0.5
Bases of Macadam																
Crushing	1.0	-	1.0	-	1.0	-	1.0	-	0.8	0.1	0.8	0.2	0.9	0.1	0.9	0.1
Additional Work	1.0	-	1.0	-	0.8	0.2	0.7	0.3	-	0.3	-	0.2	0.2	0.4	0.2	0.2
Fine Grading before Paving	1.0	-	1.0	-	0.5	0.5	0.4	0.6	-	0.1	-	-	0.2	0.2	0.2	0.2
Spreading Topsoil	1.0	-	1.0	-	0.7	0.3	0.5	0.5	-	-	-	-	0.2	0.2	0.2	0.1
Group IV Paving																
Crushing Rock	1.0	-	1.0	-	0.9	0.1	0.9	0.1	0.7	0.3	0.7	0.3	0.8	0.2	0.9	0.1
Group V Bridge Work	1.0	-	1.0	-	0.8	0.2	0.7	0.3	0.8	0.2	0.4	0.6	0.8	0.2	0.4	0.4
Group VI Water and Outflow Work	1.0	-	1.0	-	0.5	0.5	0.3	0.7	0.3	0.7	0.3	0.6	0.5	0.3	0.2	0.5

Table 8

Increase in Cost Caused by Excavation in Frost Compared to Insulation Against Frost (After 6)

Work performed in the summer = 100. The cost shown includes breaking, loading, transporting, spreading, compacting, fine grading slopes, and correcting settlements. Frost Risk Group: I-not liable, II-moderately liable, III-highly liable.

Kind of Soil Method of Excavation * = Insulation against Frost	1 ft. Frost Depth 0"	12"	27"	1 1/2 ft. Frost Depth 0"	12"	27"	8 ft. Frost Depth 0"	12"	27"	16 ft. Frost Depth 0"	12"	27"
Sand and Gravel (Frost Risk Group I)												
Bulldozing	100	179	230	100	162	208	100	117	149	100	108	123
*	-	-	-	175	175	175	121	121	121	111	111	111
Scraper	100	166	210	100	156	201	100	126	168	100	118	144
*	-	-	-	163	163	163	117	117	117	109	109	109
Shovel	100	217	273	100	156	246	100	108	122	100	104	112
*	-	-	-	141	141	141	112	112	112	106	106	106
Excavation by Hand	100	239	331	100	196	266	100	130	132	100	120	128
*	-	-	-	120	120	120	106	106	106	103	103	103
Moraine (Frost Risk Group II)												
Bulldozing	100	206	257	100	176	231	100	122	152	100	110	129
*	-	-	-	193	193	193	128	128	128	114	114	114
Scraper	100	191	270	100	180	261	100	132	183	100	121	152
*	-	-	-	175	175	175	122	122	122	111	111	111
Shovel	100	239	311	100	192	287	100	112	138	100	106	120
*	-	-	-	150	150	150	116	116	116	108	108	108
Excavation by Hand	100	257	314	100	212	291	100	138	164	100	122	134
*	-	-	-	117	117	117	105	105	105	103	103	103
Quicksand[1] (Frost Risk Group III)												
Bulldozing	100	231	315	100	196	259	100	123	148	100	112	129
*	-	-	-	206	206	206	130	130	130	115	115	115
Scraper	100	218	290	100	202	277	100	128	177	100	119	147
*	-	-	-	186	186	186	124	124	124	112	112	112
Shovel	100	243	333	100	194	286	100	113	137	100	109	123
*	-	-	-	156	156	156	116	116	116	108	108	108
Excavation by Hand	100	268	331	100	218	303	100	140	167	100	119	135
*	-	-	-	122	122	122	106	106	106	103	103	103
Clay (Frost Risk Group II)												
Bulldozing	100	243	329	100	202	269	100	128	156	100	117	135
*	-	-	-	207	207	207	133	133	133	118	118	118
Scraper	100	186	272	100	202	260	100	130	182	100	125	156
*	-	-	-	184	184	184	126	126	126	114	114	114
Shovel	100	255	342	100	205	301	100	112	136	100	108	121
*	-	-	-	159	159	159	119	119	119	110	110	110
Excavation by Hand	100	280	346	100	225	317	100	144	169	100	124	138
*	-	-	-	124	124	124	108	108	108	104	104	104

1. Saturated fine sand and silt.

The SBEF then sought to determine the most advantageous time to begin projects which are intended to continue all year round. The consensus of opinion was that for projects involving less than 500 m^3 (650 $yd.^3$) per cut or borrow area, the most economical time to begin work was in June or July for projects in Middle Sweden (corresponding to Northern Indiana). If the project involves more than 500 m^3 per cut or borrow area, work should begin in May, June, or July for maximum economy. Work should be started at these times so that the various construction operations can be scheduled for seasons such that the best utilization of men and machinery will result.

Because the time of finishing a project depends on paving, seeding slopes, setting signs, etc. the Swedish investigation of this aspect of work scheduling is omitted.

The SBEF's major conclusions about the disadvantages and advantages of year-round construction operations are as follows. The disadvantage is that "certain operations must be done at a time of year when they cost more than at other times of year". The advantages are that, "both contractor and state get more use out of their men and machines, with reduced cost as a result;" and "...the country is saved the cost of unemployment compensation".

A detailed comparison of these disadvantages and advantages was performed by the SBEEF by

> "...considering four road projects of different designs, each of which was considered in two different climatic areas. For each of these 8 alternatives, cost estimates were made for five cases involving differing employment requirements and starting times. Careful work planning was done for each of this total of 40 cases, the time of performance of each operation being estimated. After planning was completed and checked to ensure that the employment requirements were met (the same number of workers were employed throughout the project), the cost estimate for the project was prepared.

> "In preparing the cost estimate, the work quantity for each operation carried out during a given season was multiplied by the unit price applicable for that season. The sum of all the individual operations was augmented with certain corrective terms and the total cost of the project was thereby obtained."

Table 9 gives the results of these cost estimates. Items B1 through B4 in the table are the results of comparing the 40 cost estimates mentioned. The numbers used are based on Swedish construction conditions which are very similar to conditions in the United States. Thus it is thought that the data of this table are good first approximations for Indiana. It is evident that if projects are properly planned there is net economy in a year-round highway construction activity in Sweden... and probably in Indiana, as well.

Table 9

Summary of Cost Changes Caused by Different Construction Seasons (After 6)

Times during which construction proceeds	Nature of cost	Central Sweden	Upper Northern Sweden
Summer and Autumn only	Total cost of project	100%	100%
Year round, with steady employment of labor	Cost of project, incl.:		
	A. Increased costs for operations started at most suitable time	+ 6%	+ 12%
	B. Reduced costs for		
	1. elimination of suspension and resumption of work	- 3%	- 6%
	2. better exploitation of contractor's resources	- 8%	- 14%
	3. better exploitation of employer's resources	- 1%	- 2%
	4. lower interest charges for employer	- 1%	- 4%
	Total costs	93%	86%
	Maximum increase due to starting of operations at less suitable time	+ 3%	+ 7%

PROSPECTS FOR COLD WEATHER EARTHWORK IN INDIANA

Effects on People

Workmen engaged in cold weather earthwork in Indiana can be expected to work at 75 to 100 % of efficiency relative to optimum conditions. This conclusion was reached by studying Table 1 in connection with the cold weather conditions which prevail in Indiana (115). The efficiency is dependent upon the detailed operation. For example, if the air temperature is - 5°F. a workman exposed to the cold, such as a technician performing density tests, can be expected to operate at no more than 75% of his optimum efficiency. On the other hand, under the same conditions an equipment operator in a heated cab can be expected to operate at about his optimum efficiency.

Windchill[1] at four locations in Indiana at various times of the year was determined by studying U. S. Weather Bureau records (110). These records were kept at major airfields for five to ten years and therefore reflect the average values of windchill to be expected at an exposed location. Naturally, if shelter such as a grove of trees is close by, lesser windchill values are to be expected. Table 10 shows the percent of time during the months from September through April when windchill can be expected to have the following values:

1. See page 4 for the development of windchill values.

Table 10

Windchill Values in Indiana During Fall, Winter, and Spring Months

Table shows percent of time during month having given windchill values.

		S. Bend	F. Wayne	Indpls.	Evansville
Month: September					
Windchill	Under 600	94	95	96	99
	600-1000	6	5	4	1
	1000-1400	0	0	0	0
	Over 1400	0	0	0	0
October	< 600	63	65	64	81
	600-1000	37	35	36	19
	1000-1400	0	0	0	0
	> 1400	0	0	0	0
November	< 600	21	20	28	40
	600-1000	60	64	59	53
	1000-1400	19	16	13	7
	> 1400	0	0	0	0
December	< 600	4	5	8	17
	600-1000	58	60	62	69
	1000-1400	35	32	29	14
	> 1400	3	3	1	0
January	< 600	1	6	5	12
	600-1000	43	51	55	65
	1000-1400	51	41	37	22
	> 1400	5	2	3	1
February	< 600	1	4	7	20
	600-1000	49	60	65	64
	1000-1400	46	33	25	15
	> 1400	4	3	3	1
March	< 600	7	12	17	37
	600-1000	63	67	64	55
	1000-1400	30	21	19	8
	> 1400	0	0	0	0
April	< 600	41	49	55	71
	600-1000	55	48	44	28
	1000-1400	4	3	1	1
	> 1400	0	0	0	0

Under 600: "Varies from "Hot" to "Very Cool", (generally for adequately dressed workmen).

600-1000 : Workmen definitely become cold and uncomfortable as windchill approaches 1000, but working efficiency is only slightly decreased.

1000-1400: Outdoor work is very unpleasant in this range; working efficiency is seriously decreased; frostbite is a serious danger as windchill approaches 1400.

Over 1400: Outdoor work for more than a few minutes is impossible without special arctic clothing; working efficiency is very low.

Figure 10 shows the percent of time when windchill values are over 1000 for the four stations of available data.

The highway user in Indiana can also be affected significantly, if indirectly, by cold weather earthwork. The benefits to users can be of two types, added safety and reduced inconvenience. Added safety will accrue because higher capacity (and therefore safer (1)) highway facilities will be available at an earlier date if earthwork is continued into or through the cold weather season. The user will benefit from reduced inconvenience because the period during which he must drive on older facilities, or through hazardous construction areas (28), or take detours around them will be reduced. This matter of reduced construction period hazard and inconvenience is especially important in urban projects where a very large volume of traffic must go through or around the construction area daily. The potential economy to the highway user is discussed in a later section.

Effects on Construction Equipment and Methods

Most construction machinery will require special winterizing and maintenance as spelled out previously on pages 8-10. Engine starting is a problem and special starting equipment may be desired. Heated cabs are

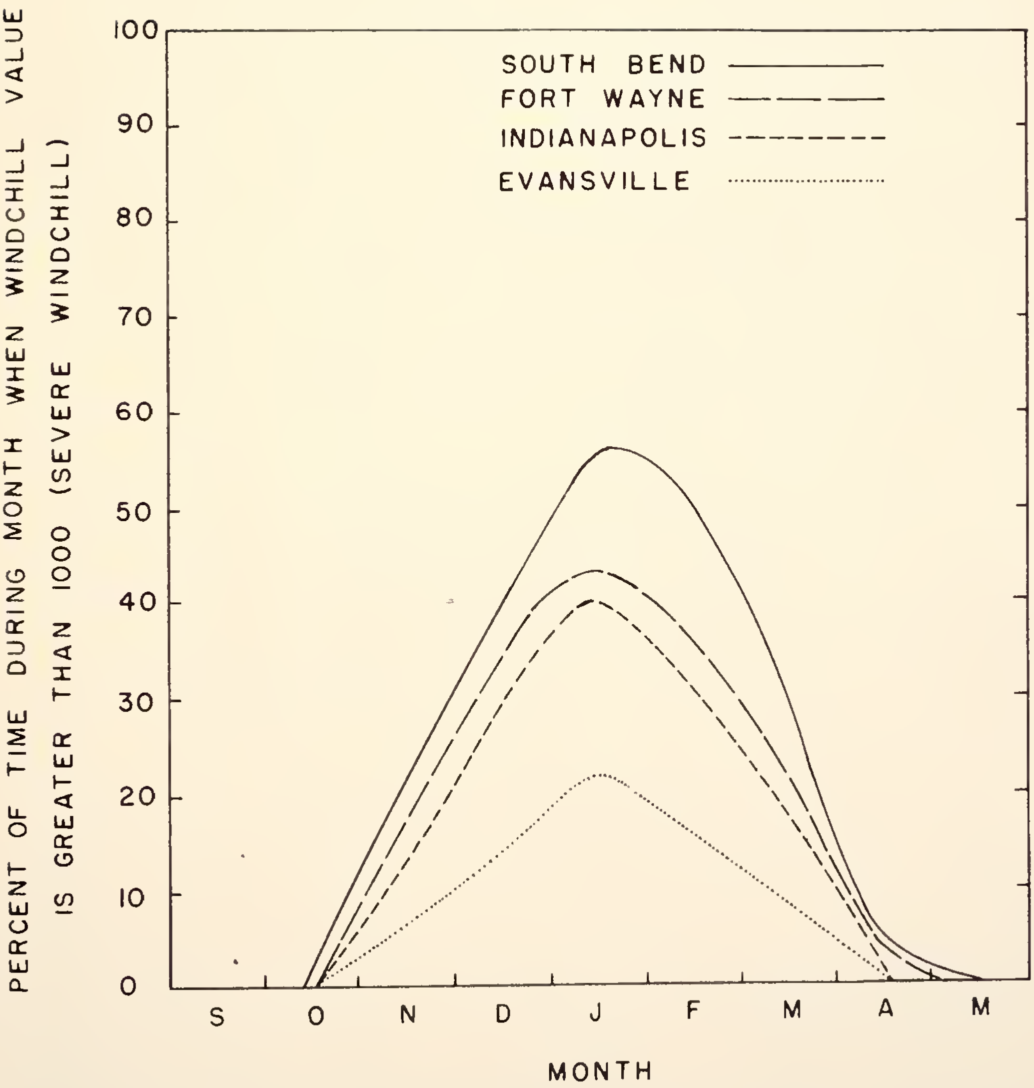


FIGURE 10. PERCENT OF TIME WHEN SEVERE WINDCHILL OCCURS

needed to maintain high operator efficiency. Special equipment may be needed for ripping frozen soils and for disaggregating frozen soil chunks. As shown in Table 2, construction machinery can be expected to suffer a small loss in operating efficiency when used under Indiana cold weather conditions. However, most of the time (115) this loss in efficiency should not exceed 10%.

Current Indiana normal weather earthwork practices will need to be modified somewhat in order to do efficient cold weather earthwork. The unique features have been described in the section on Present State of Cold Weather Earthwork Practice. The following practices should be considered when planning cold weather operations in Indiana.

(1) The ramp method of placing fill, as shown in Figure 5.

(2) Placing frozen or too-wet soil as berms or as the outer shell of embankments, as shown in Figure 3.

(3) Pushing a frozen crust (which may form on the embankment under construction at night or over weekends) off the side of the embankment where it can be shaped when thawed in the spring.

(4) Working a borrow area 24 hours a day in sub-freezing weather.

(5) Ripping frozen soil to permit loading in scrapers.

(6) Mixing soil which is too wet for compaction with drier soil to form a mixture which can be compacted to the required density.

(7) Placing alternate lifts of frozen or too-wet soil and free draining granular soil followed by rolling after thawing and drying in the spring.

Since only certain kinds of operations are suitable for performance as cold weather operations (Table 7), scheduling becomes more critical. Inadequate attention to this aspect of the work can produce great economic disadvantage. It is particularly important to monitor soil conditions in excavation areas. Depths of freezing, if any, must be known. Since adjustments of natural moisture contents may not be practicable, it must

be predetermined that the natural moisture content is suitable for compaction. At present, we cannot predict the moisture content of a particular Indiana soil for a particular time of year (see the following section on Soils), and sampling is required. In fact, it may be necessary to sample a number of times as the weather changes. However, such sampling can prevent heavy machinery being moved onto the area only to discover that the deposit is unworkable. There is supporting evidence (Table 6) to indicate that only fills above a limiting size should be constructed in cold weather.

Experimentation along the lines suggested in this section is necessary to develop requisite cold weather construction technology for the climatic conditions of Indiana.

Effects on Soils

Soils in Indiana are of glacial origin in the northern 2/3's of the State. In the southern 1/3, some of the major valleys contain glacial valley train deposits, but most of the remainder of the soils are residual, derived from shale, sandstone, limestone, or combinations thereof. The deposits of sand and gravel in Indiana are primarily glacial. Figure 11 shows the distribution of the larger deposits. The other soils in the State have high percentages of silt and clay sizes. These may be characterized as loams, silt loams, and clay loams.

Based on experience in the appropriate climatic zones in Sweden (6), sand and gravel earthwork done in cold weather in Indiana will cost 8 to 79% more than in the summer. The percent increase will depend on the operation, machine, and method involved. For example, if a bulldozer is used to excavate a small cut to a depth of 2 feet in northern Indiana,

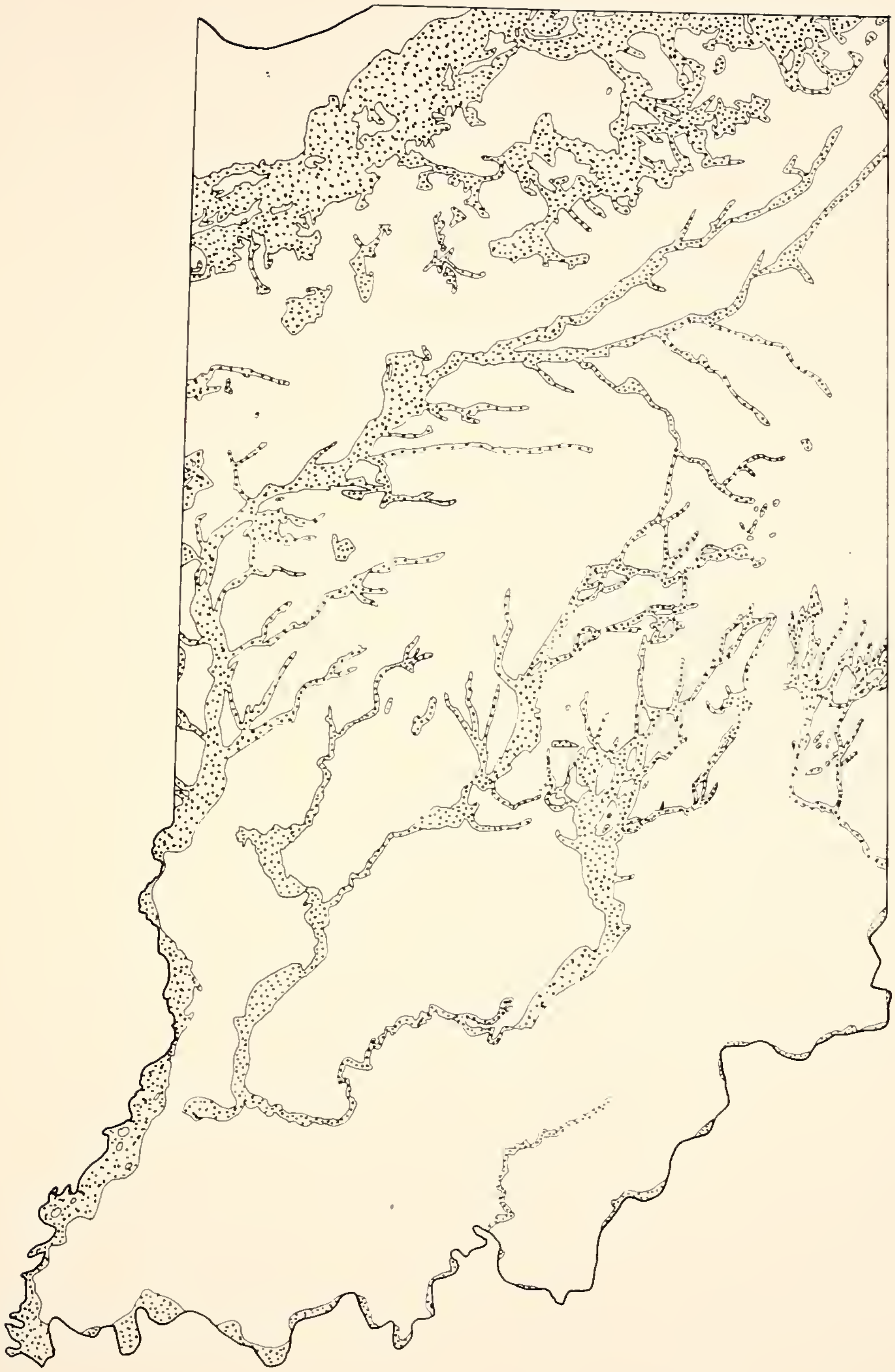


FIGURE 11. MAP OF INDIANA SHOWING GLACIAL DEPOSITS OF SAND AND GRAVEL.

(Traced from Map of Indiana showing glacial deposits, Report of Progress No 17, 1960, Indiana Geological Survey)

the operation might cost 79% more in the winter. However, if a power shovel or front end loader is being used to load trucks in a pit in northern Indiana, the operation might cost only 8% more in the winter.

When placing sand and gravel in cold weather, normal compaction specifications are practicable, assuming water contents are low enough to prevent frozen aggregations or "chunks." In fact even if such chunks do form, the specifications can usually be met with vibratory steel rollers or grid rollers used to disaggregate them (61).

Fine grained soils, or even granular soils with appreciable fines, will be more expensive to handle in the winter. Again the increase in cost will depend on the soil type, the operation performed, and the machine and methods used. For example, if a bulldozer is used to excavate a small cut 2 feet deep in glacial till in northern Indiana, the operation might cost 85% more in the winter. However if a power shovel or front end loader is being used to excavate a deep cut in the same glacial till in northern Indiana, the operation might only cost 14% more in the winter. If a scraper is used, the cost might be 42% higher in the winter. Of course it must be remembered that the base (summertime) cost of excavation with a power shovel or front end loader is higher than that with a scraper.

As mentioned in the previous section, the natural water content of the borrow strictly controls whether it is feasible to place that soil as fill, because adjustment of the water content is generally inadvisable in cold weather. Therefore, the author investigated the in-situ water contents of Indiana soils in relation to their optimum water contents.[1] The data used for these studies was obtained from subsurface investigation

1. The Standard AASHO (laboratory) optimum is used for convenience. The field optimum is, of course, dependent upon the details of the field compaction operation.

reports for Interstate Highway routes in Indiana (50), and from agricultural soil moisture studies on Purdue experimental farms. The former reports were obtained from the Indiana State Highway Commission and the latter data came from the Agronomy Department of Purdue University (9,118, 119) and from U. S. Weather Bureau Records (109).

The data extracted from the Interstate Highway reports were:

(1) Textural and AASHO Classifications
(2) Water content
(3) Depth of sample
(4) Horizon of sample
(5) Date of sampling
(6) Maximum dry unit weight[1]
(7) Optimum water content[1]

Figure 12a shows the locations in Indiana where the checking was accomplished, and is overlayed on Figure 12 showing the physiographic subsections of Indiana (91). The samples selected for study were those which represented soils likely to be excavated for fill...those from level plains and from the sides of hills.

The optimum compaction water content for each soil stratum was subtracted from the water content of each sample in that stratum. This deviation in water content from optimum was then plotted versus the date of sampling. Figure 13 shows this variation with time. The scattering is caused by a variety of local ground and climatic factors. A line of means drawn through the plotted points showed no seasonal trend. However, the mean lines are nearly always above the optimum. About 23 percent of all the samples were within ± 2% of the optimum.

1. Standard AASHO (laboratory) values for each sampled stratum.

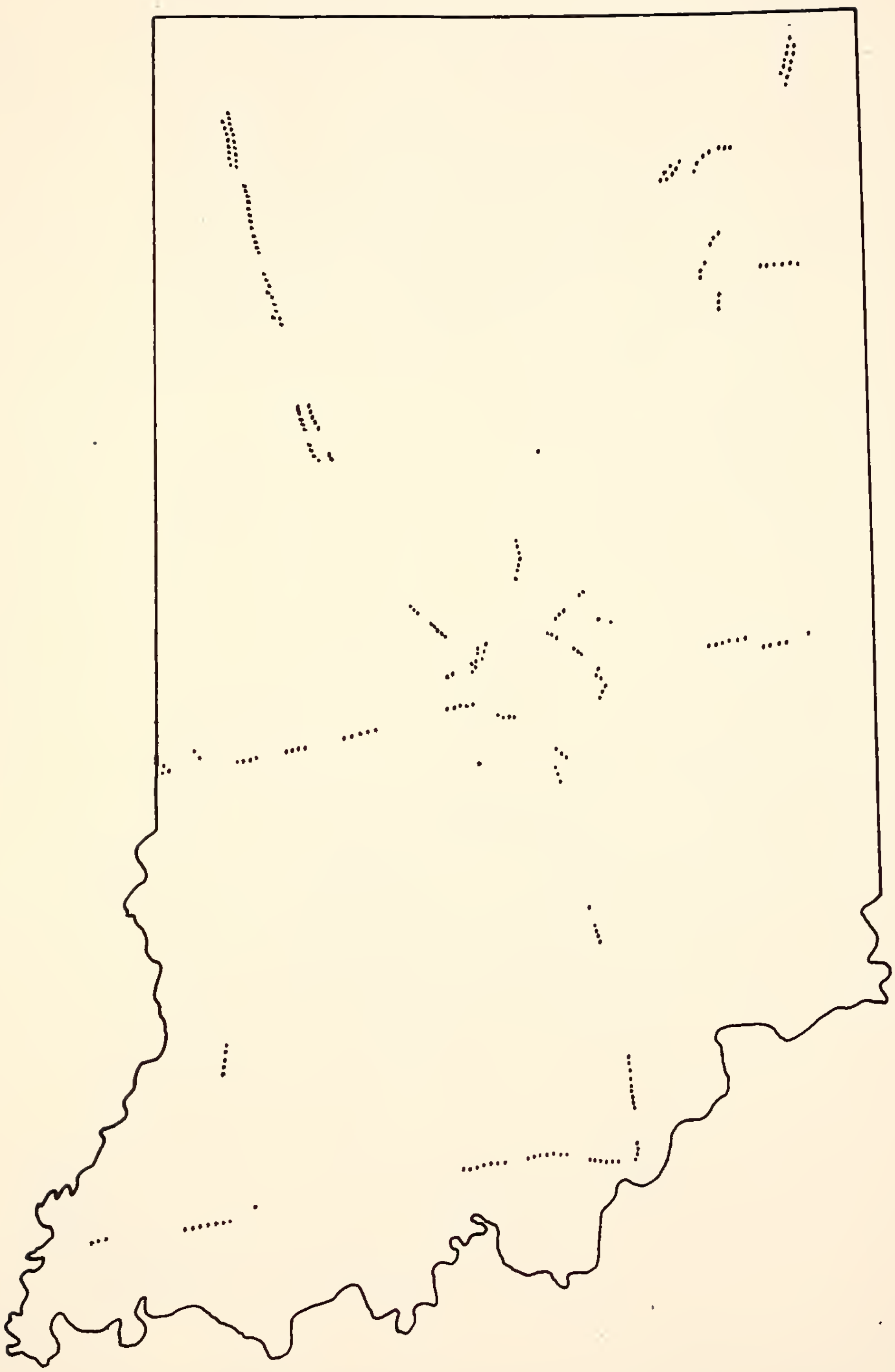


FIGURE 12a. LOCATIONS OF SOIL SAMPLES USED IN ANALYSIS

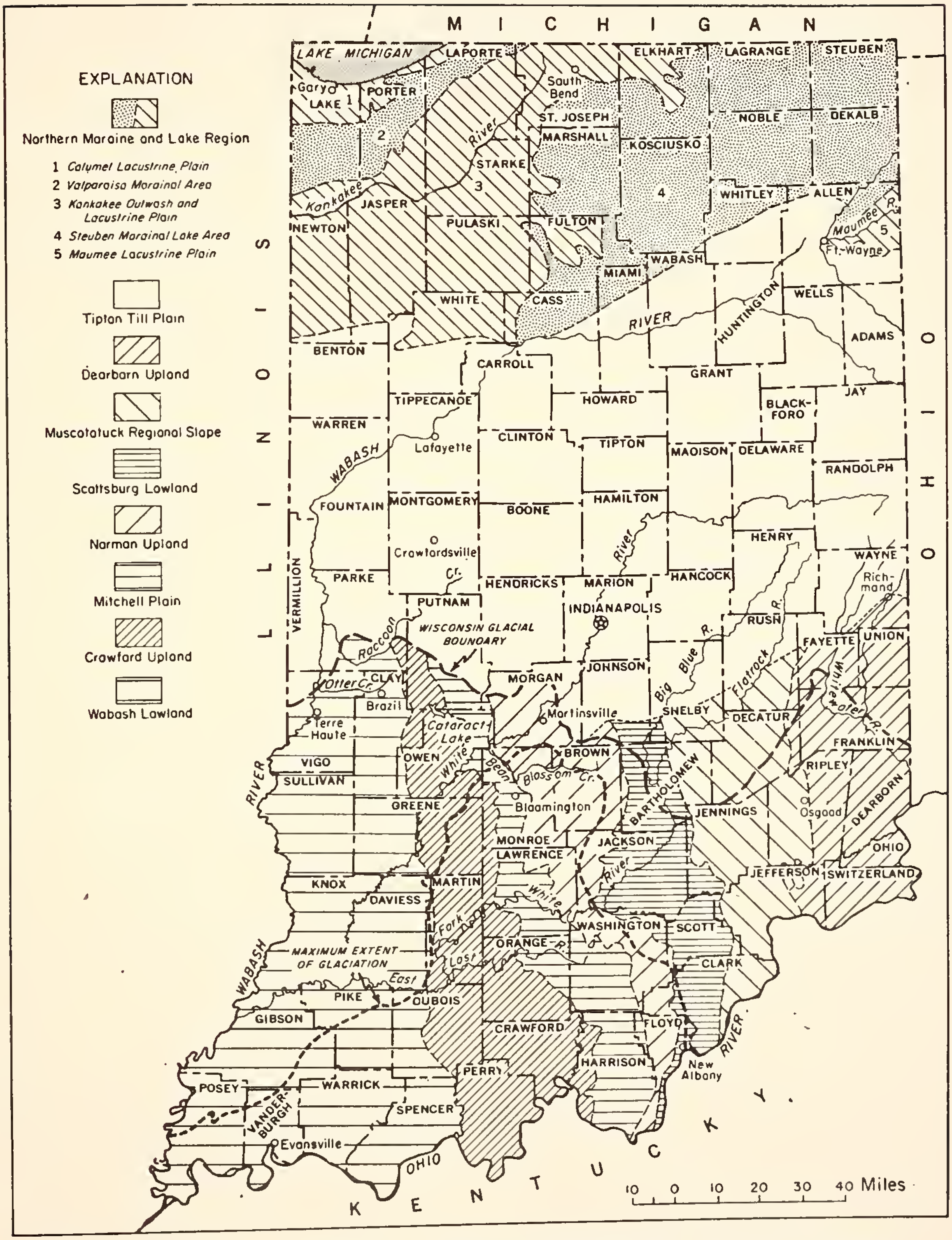
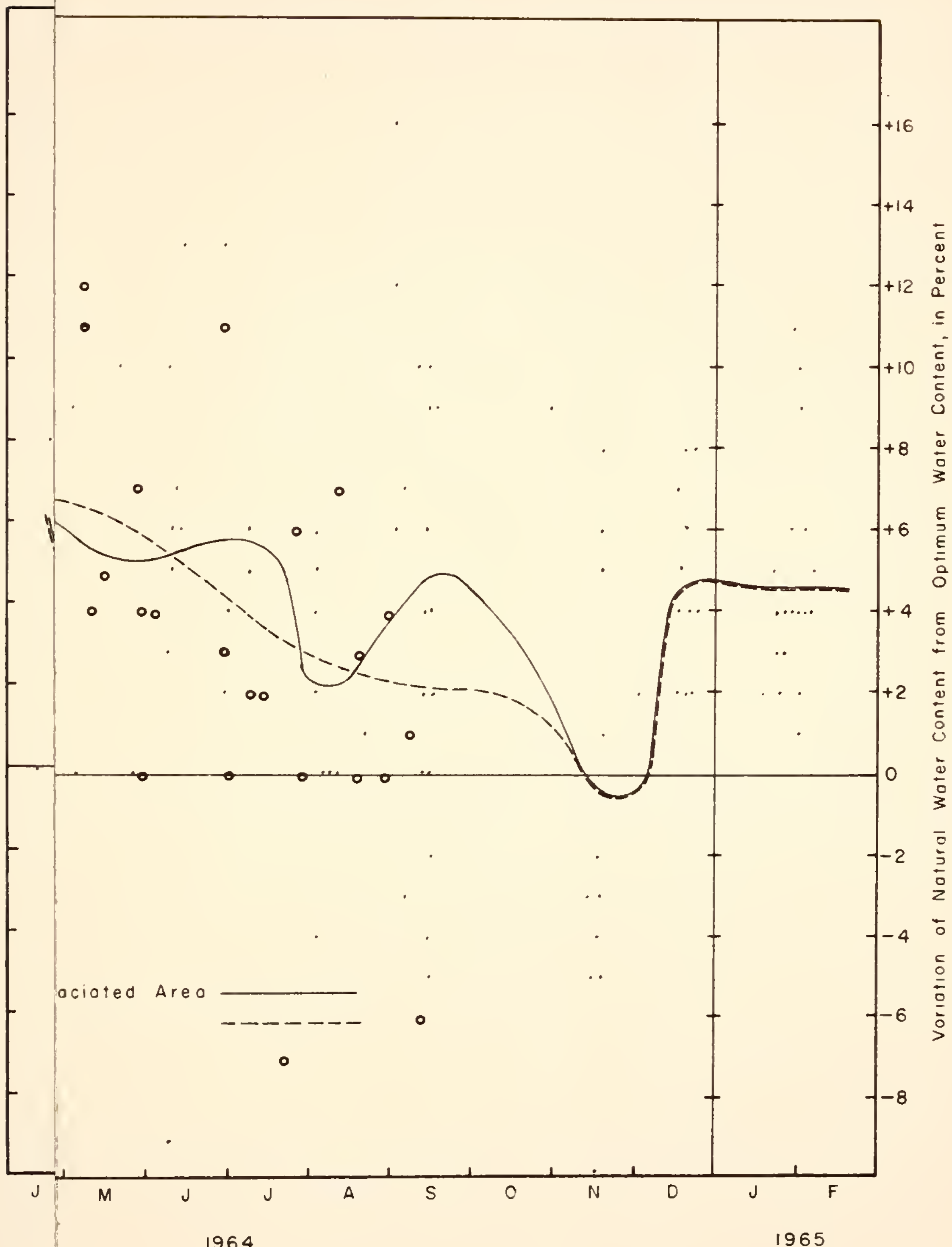


Figure 12. Map of Indiana showing physiographic units and glacial boundaries. Modified from Indiana Geol. Survey Rept. Prog. 7, fig. 1.
(From 91)



+16
+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
Variation of Natural Water Content from Optimum Water Content, in Percent
aciated Area
J
M
J
J
A
S
O
N
D
J
F
1964
1965

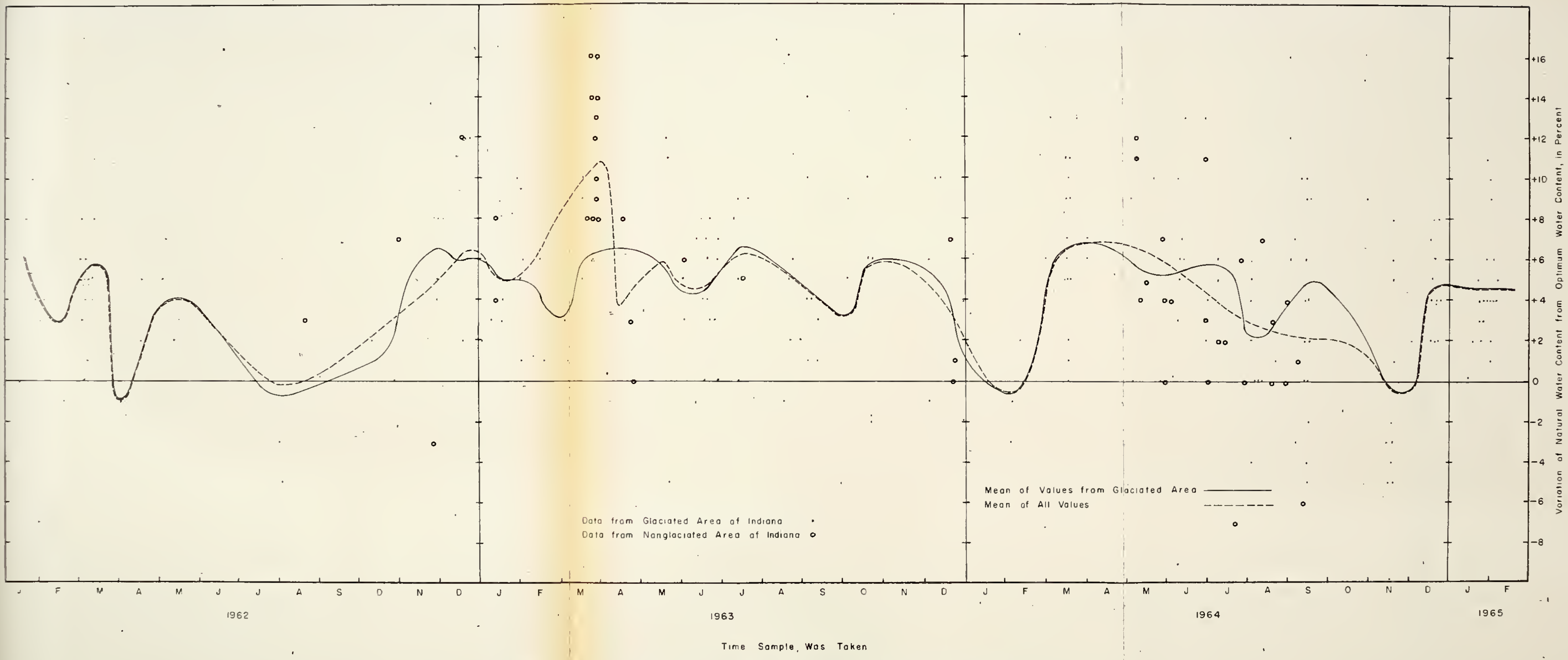


Figure 13. Selected Water Content Variations of Indiana Soils

The above data are for many soils at many different times. In order to study the seasonal variation in water content for the same soils, data from the soil moisture studies (9,118,119) of the Agronomy Department of Purdue University were used. The studies have been carried out for six years at three different Purdue experimental farms: the Agronomy Farm in Tippecanoe County, the Sand Field in Marshall County, and the Forage Farm in Lawrence County. At each farm, soil moisture measurements are made at irregular intervals, ranging from once a month to once a day, during the cultivation seasons. Unfortunately, no measurements are made during the middle of the winter. The measurements, made with a nuclear probe, are summarized in Figures 14 and 15. Because the soils in which the soil moisture is being measured could not be obtained for testing, optimum compaction moisture contents were assumed. Although the soil moisture is usually lowest in the late summer and fall, it sometimes varies several percent within so short a time period as a month. Thus an actual measurement is the only way to know definitely the water content at a given place and time.

Other Materials

Rock blasting, loading, and crushing operations are good examples of work which is economically accomplished in the wintertime. Table 6 shows that these operations may cost only 2% to 5% more under Indiana winter conditions.

Peat excavation for waste (replacement) is also a desirable winter operation. Table 6 shows that such excavation may cost 6% less in the winter, due to easier access on frozen ground.

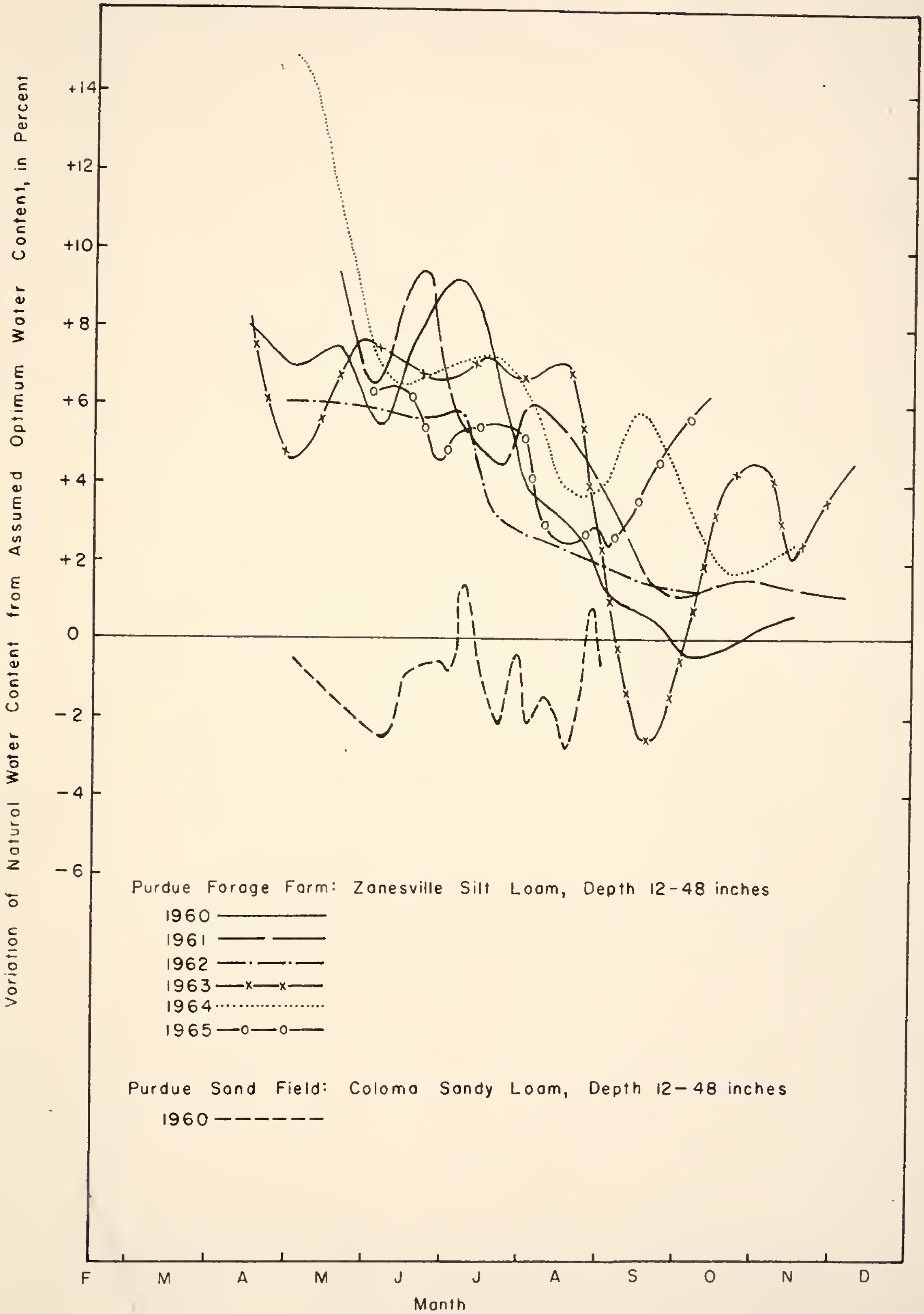


Figure 14. Yearly Variation in Natural Water Content — I

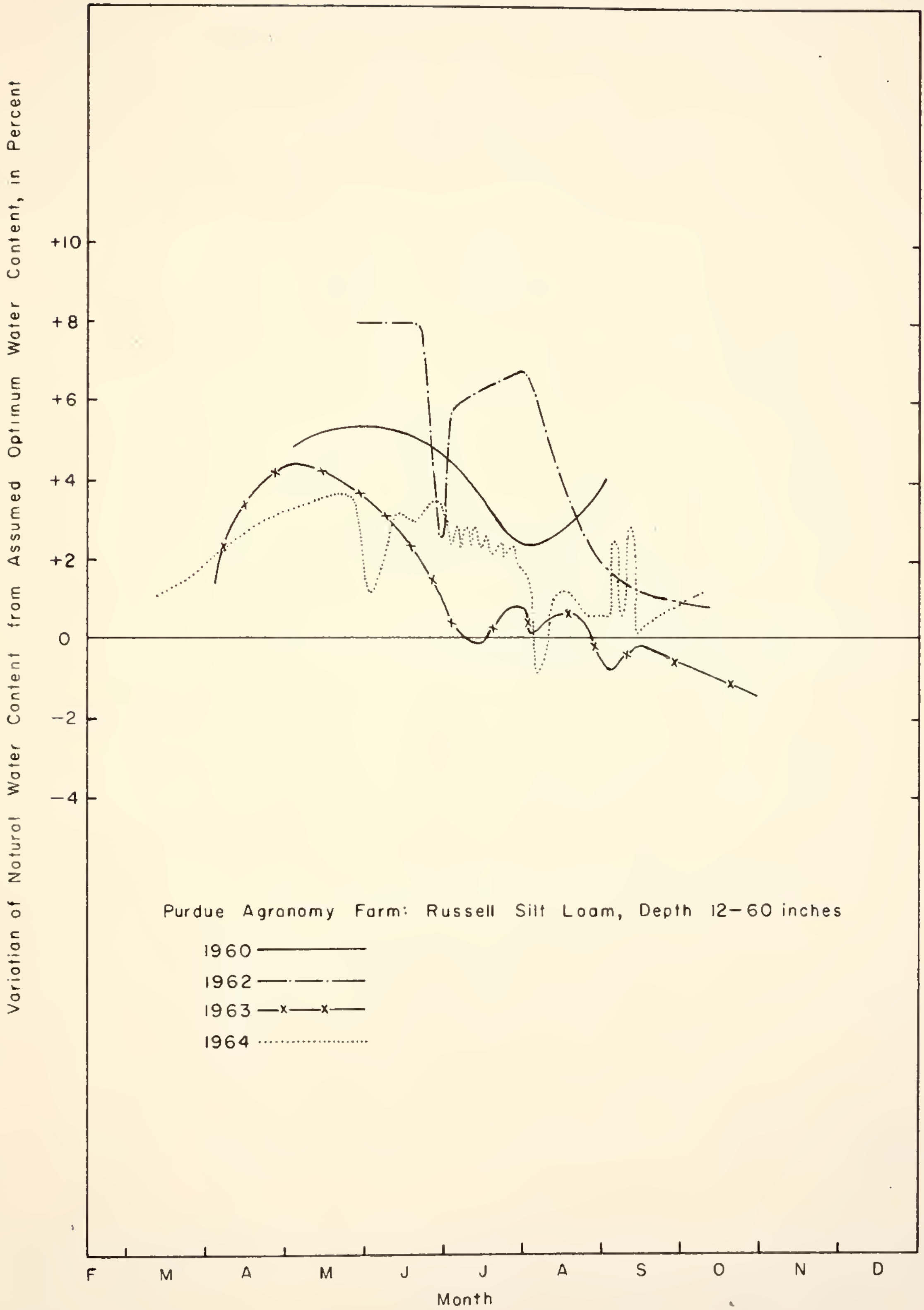


Figure 15. Yearly Variation in Natural Water Content – II

As shown in Table 4, several Indiana contractors already recognize the advantage of doing rock work and peat excavation in cold weather. Also, as shown in this table, contractors cite the availability of more rock work and peat excavation as factors which would encourage more cold weather earthwork in Indiana.

Economic Feasibility

It is obvious that the unit cost of most earthwork operations is higher in cold weather than in warm. However, other benefits may accrue which provide economic justification for working at times which are less than ideal. In justifying such activity, one must define the degree of climatic adversity being dealt with. For example, doing earthwork on a dry, sunny day in November when the temperature is 35° will almost certainly be justifiable; whereas earthwork in a January blizzard when the temperature is -15° will almost certainly not be justified.

In any event, the kinds of benefits which could be derived should be considered in greater detail. These are of two types: (1) those which result from an earlier completion date, and (2) those which result from a "continuous" rather than a seasonally interrupted operation.

Inflation and interest are the more simple benefits to define numerically on a short term basis...that is, over the construction period of a project. Assuming an inflationary cost drift of 3% per year, which is currently viewed as not excessive in this country, the inflation rate per month is 1/4% of the annual cost for each month's reduction of time[1] of

1. Working 1 month longer than the conventional season will reduce the normal project completion time by some fraction of 1 month. In northern Indiana this fraction should average about 1/2 over the 4 winter months (Figure 10). Thus, working 2 winter months should reduce the project completion time 1 month.

finishing the project. The economy to the contractor is direct, while that to the State is indirect in that it is merely reflected in bid prices. Likewise, the State will not directly benefit from interest savings unless the facility under construction is to be a revenue earning project. However, when a contractor finishes a job earlier, interest charges on money borrowed to finance his operation may be reduced. A yearly interest rate of 7% is typical of charges for money borrowed by contractors to finance their operations. At any given time during a construction project the amount of money which a contractor must borrow to finance his operation will be the difference between his cost on the project to date and the State's payment for the project to date. For work performed in Indiana, it will be assumed that this lag in project financing can be equated to one-fourth of the annual construction costs for the project. Thus, the interest benefit to the contractor for finishing 1 month sooner will be (.58% x 1/4) = .15% of the annual cost of the job. The sum of the inflation and interest benefits assignable to cold weather earthwork thus amounts to .40% of the annual cost of the project for each month that the normal project duration is reduced.

A benefit which is somewhat more difficult to calculate, but which is higher in value, is the reduction in accident losses due to earlier availability of a safer facility. For simplicity, the cost of accidents on Interstate Highways and other older highways will be prorated on the basis of fatal accidents only. This is a conservative estimate because the property damage rate per fatality on the older highways is higher than on the Interstates (1). Recent statistics from Whitton (75) show: "On completed sections of the Interstate System the fatality rate is 2.8 deaths per 100 million vehicle miles, compared with a rate of 9.7 on

older highways in the same traffic corridors." Assume that both the new Interstate and the older highways carry the same Average Daily Traffic (ADT) of 15,000 (1)[1]. This is realistic because the Interstate will draw traffic away from several roughly parallel old routes. On this basis, there will be 0.15 death per year on the average mile of Interstate and 0.55 death per year on the average mile of older highway. The National Safety Council recommends (1) that when making economic comparison of accidents, the total cost of all accidents per year (whether they be fatalities, personal injuries, or personal property damage accidents) should be divided by the number of fatalities per year in order to obtain a figure of accident cost/death. The facilities in question can thus be compared economically on the basis of deaths per year. With the current cost of all traffic accidents of $8,900,000,000 and 49,000 deaths per year (77), the reduction of 0.40 death per mile of Interstate per year represents an economic savings of $73,000 per mile of Interstate per year, or $6,100 per mile per month. Thus, if cold weather activity permits a mile of the Interstate system to be available one month earlier, accident losses will be reduced by $6,100.

There are certain travel delays incident to the existence of construction areas because the motor vehicle must continue on the old route or follow special detours of some sort. The economic consequence of such extended travel time is greatest in urban mileage. Let us assume that 5,000 persons are delayed 5 minutes per day by a typical section of new highway under construction. If the value of travel time is taken as $0.86

1. The new Interstate will actually carry more traffic than the old highways being replaced because the new facility generates traffic. Therefore the figure (15,000) used for comparison should be the traffic volume carried by the old routes.

per person per hour (1), the delay means $10,700 per month. Where construction activity requires detouring of high traffic volumes, accident costs may rise well above these cited above for normal highway operation. Shortening the construction period will produce additional safety and economy, and although this topic is currently under study by the California State Highway Department (28), no numerical values are presently (1967) available.

Although items of increased safety and convenience of traveling may not directly influence the financial operations of either state highway organizations or contractors, the public welfare is significantly benefited by them. Therefore, these are valid economic allowances in the overall justification of cold weather earthwork.

Another category of benefits includes those which result from a continuous utilization of construction resources. These are considered under three general headings: the resource of labor, the resources of contractors, and the resources of the State.

The resource of labor, defined as those nonsupervisory persons normally engaged in earthwork operations, is largely nonproductive during cold weather shutdowns. Most of these people become seasonally unemployed and qualify for unemployment compensation. In Indiana (49) this compensation is normally $40 per week. Thus a benefit of $40 per week per worker employed, results from each week of work during cold weather.

In addition to the regular state unemployment compensation systems, organized wage earners in northern states have an effective seasonal unemployment compensation in the form of higher wages. Thus a worker in the North earns as much in 8 or 9 months as his counterpart in the South does in 11 or 12 months. On the basis of recent United States Department

of Labor statistics (112) the average contract construction worker in Indiana receives \$4.33[1] per hour, while in the South (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and South Carolina) he receives \$3.68[2] per hour. Only part of this difference can be attributed to the length of construction season. For purposes of this study let us assume that 50% of the differential can be so ascribed. With an average work week for Indiana contract construction workers of 38 hours (112) a benefit of \$12 per week per worker can be realized. This benefit accrues whenever workers are employed year round. Therefore a proportion of it should be calculated for the entire construction season when cold weather earthwork (which will reduce the wage differential) is being contemplated. The proportion (of the \$12/week benefit) to be used should be:

$$\left(\frac{\text{no. of months extension of season contemplated}}{\text{no. of months workers were previously inactive}}\right)$$

Wage adjustments would not occur immediately, but over a period of time the differential in southern and northern wages occasioned by the seasonal factor should substantially diminish.

The resources of contractors are defined as supervisory and professional personnel and capital investment. The cost of maintaining these resources continues year round whether or not they are in effective use. The best source of information on the real economic benefits of better utilization of the contractors' resources comes from the Swedish (SBEF) study (6, p. 13), where it is concluded that a saving of 2% of the total annual construction cost of a project will accrue for each month that suspension of operations is avoided. Also, if the project is carried out

1. Pro rated on the basis of Illinois and Ohio wages
2. Pro rated on the basis of the average of all gross hourly wages in the states listed.

all year round, an additional benefit of 3% of the total yearly cost of the project will accrue through elimination of the expense of suspending and resuming work.

The resources of the State might also be better utilized by a program which sustained earthwork operations throughout the year...with particular reference to the personnel and facilities of the construction division. Said personnel and facilities would no longer be shifted to secondary functions in the winter, but could continue in their normal jobs throughout the year. Despite the adjustments in the current operational procedures in the various divisions which would be necessitated by more winter work, the SBEF study indicates that once these adjustments have been effected, a saving of perhaps 1% of the total cost of a project may be realized. This benefit is occasioned by a shifting of operations from an 8-month to a 12-month base...or (assuming that this benefit can be pro rated) a gain of 1/4% of annual project cost per month's extension of work in the cold season.

Table 11 summarizes the benefits which could accrue if the elapsed calendar time for project completion were to be reduced one month by extending the construction season by an additional two months.[1]

Size of Projects

The scheme of implementing year-round earthwork operations is clearly favored by construction project sizes which are sufficiently large to insure that a variety of operations suitable for performance during the cold weather period are included in the contract. For example, a contract for say $\pm$ 5 miles of Interstate would include rock cut, sand fill, excavation

---

1. See footnote 1, page 56.

for waste, deep cut or large embankment , or other such features suitable to be operated on during cold weather. Thus cold weather operations produce an additional factor to be considered in the decision as to contract project length.

Example of Benefit Calculation

Consider the application of the values of Table 11 to a numerical example. A rural Interstate construction project in northern Indiana is 5.3 miles long and would normally cost $7,200,000. Construction is estimated to require 18 calendar months if earthmoving is carried on on a

Table 11

Summary of Economic Benefits Derived from Finishing One Month Earlier by Working Two Months Longer

Source of Benefit (Conditional Assumptions)	Benefit as % of Annual Cost of Urban Project Unless Otherwise Stated
A. Less Inflation and Interest	.40%
B. Reduced Accident Losses (15,000 ADT, Limited Access)	$6,100/mile
C. Reduced Construction Area Delays (5,000, 5 min. delays/day)	$10,700/month of earlier finishing
D. Reduced Unemployment Compensation (4 1/3 weeks/month)	$346/worker
E. Reduced Wage Differential[2]	$24 $(\frac{N_W}{N_I})$/worker
F. Better Contractor Resource Utilization[3] (Conventional season was 8 months/year)	4%
G. Better State Resource Utilization (Conventional season was 8 months/year)	1/2%

1. Rural project figures would be the same except for a reduced value for (C).
2. $(\frac{N_W}{N_I})$ is $\left(\frac{\text{no. of weeks total working season planned}}{\text{no. of months workers were previously inactive}}\right)$
3. Bonus benefit if working 12 months/year...3% of Annual Cost of Project.

normal season (8 months/year) basis; or 17 calendar months if earthmoving is carried on 10 months/year; or 16 calendar months if earthmoving is carried on 12 months/year. It is assumed that the project will be started in May so that only one winter season is being considered. Upon completion the highway will carry an ADT of 14,000. During construction an average of 15 nonsupervisory workers will be employed in the earthmoving phases of the project. The size of the project is sufficient to permit suitable operations to be performed during cold weather.

The benefits which will accrue each month during which construction is carried on during the normally inoperative cold weather period (assumed to be 4 months) are as follows: N_c is the number of calendar months in the construction period.

Reduced Inflation and Interest: $(.0040 \times \frac{7,200,000 \times 12}{N_c} \times \frac{1}{2})$ $= \$\ 173,000/N_c$

Reduced Accident Losses: $(6,100 \times 5.3 \times \frac{14,000}{15,000} \times \frac{1}{2})$ $= \$\ 15,100$

Reduced Unemployment: (173×15) $= \$\ 2,600$

Reduced Wage Differential[1]: $(\frac{1}{4} \times 15 \times 12 \times N_w)$ $= \$\ 45\ N_w$

Better Contractor Resource Utilization: $(.02 \times \frac{7,200,000 \times 12}{N_c})$ $= \$1,729,000/N_c$

Better State Resource Utilization: $(.0025 \times \frac{7,200,000 \times 12}{N_c})$ $= \$\ 216,000/N_c$

(Bonus for working 12 mo./year): $(.03 \times \frac{7,200,000}{1.25})$ $= \$\ 172,800$

N_c	16	16 1/2	17	17 1/2	18
Sub Total	$152,300	$148.500	$144,200	$140,400	0
Bonus	172,800				
Rounded Totals	$324,000	$149,000	$144,000	$140,000	0

1. See footnote 2 page 62.

If this total benefit is expressed as a percent of the monthly average cost of construction, it can be compared with the increased cost of construction (or the reduced production rate if cost is to be held constant) during the months in question. Table 12 shows this percentage of benefit/construction cost for four increased lengths of construction season.

With the benefits of doing cold weather earthwork on this project now known, operations can be selected for performance during the cold months which will keep the increase in construction costs below the benefits determined. Thus, column D in Table 12 is the upper limit of increased construction costs which can be tolerated during the cold months without sacrificing net economic gain by doing cold weather earthwork. Suitable operations can be selected by consulting the experiences of others (Table 6), and ultimately by reference to data accumulated for Indiana.

Table 12

Total Benefit Due to Cold Weather Earthwork Compared to Monthly Average Construction Cost for Different Lengths of Working Season[1]

Working Season Increased from 8 months to	Monthly Average[2] Construction Cost $	Monthly[2] Benefit $	Monthly Benefit/Monthly Average[3] Const. Cost %
9 months	596,000	140,000	23
10 months	575,000	144,000	25
11 months	557,000	149,000	26
12 months	540,000	324,000	60

1. For example project described on page 61.
2. Rounded to nearest $1,000. Adjusted for number of months actually worked.
3. Rounded to nearest percent.

SUMMARY

1. The present "state of the art" with respect to cold weather earthwork was reviewed.
2. An assessment was made of the technological deterrents to cold weather operations: (a) equipment operation and performance, (b) human efficiency, (c) soil temperature and moisture conditions. This was accomplished by interpolation of data from other geographical regions to Indiana and by direct evaluation of the Indiana environment.
3. The benefits to be derived from an earlier project completion, effected by cold weather operations, were categorized as to: (a) the highway user, (b) the labor resource, and (c) contractor and state highway organizations.
4. The comparative economics of winter shut-down vs. selected cold weather earthwork operations were illustrated by example...for Indiana.

CONCLUSIONS

1. The technology of cold weather earthwork has been significantly developed by Scandinavian countries, Canadian provinces, and northern states of the U.S. These experiences provide a substantial base for further experimentation in Indiana.
2. Selected operations such as rock excavation, excavation and wasting of organic materials, and excavation for compaction of relatively dry granular materials are presently feasible throughout the year in Indiana. There may be real economic benefit in scheduling these operations for the cold season.
3. Reductions in human and machine efficiencies induced by the Indiana Winter are generally minor. However, soil temperature and moisture conditions can introduce special problems.
   a. Wet-frozen granular materials require special rolling to break down the larger frozen aggregations.
   b. Frozen fine-grained soils cannot be adequately compacted and must be either wasted or used in selected non-critical portions of a fill.
   c. Alteration of the natural water content of unfrozen excavated material prior to compaction is not generally feasible. This leads to either, (1) wet-side compaction or (2) deferral of compaction to a time of more favorable moisture condition.

   d. Special expedients may be required to minimize the quantities of frozen soil being handled. These include, (1) around-the-clock excavation, placement, and compaction, and (2) placement and compaction by the ramp method.

4. Since cold weather earthwork can advance the completion data of a primary highway construction project, a number of public benefits accrue which can be expressed (at least approximately) in terms of dollars. These benefits include (a) reduced charges for interest and inflationary drift, (b) reduced accident costs, (c) reduced travel delays, (d) reduced unemployment compensation, (e) improved employer-employee relations, and (f) improved utilization of the resources of both contractor and state highway organizations.

5. When viewed in their entirety, with considerations of compatible scheduling and of all economic benefits, it is likely that most large highway projects in Indiana are economically as well as technically feasible for scheduling as year-round construction operations.

6. While the knowledge accumulated to date is encouraging, the uniqueness of the Indiana highway construction operation has not been defined in sufficient detail to justify implementation of a large scale experimental program in cold weather earthwork. Further study is required.

RECOMMENDATIONS FOR FURTHER STUDY

Based upon the encouragement of the generalized and somewhat simplified findings of this study, a three-pronged research extension is in order, focusing upon the uniqueness of the highway planning, design and construction functions in Indiana.

1. An important part of the economic justification of cold weather earthwork lies in the earlier availability of a safer and more convenient facility to the highway user. These benefits need to be quantified as to magnitude and distribution among various classes of users.

2. It is also contended that year-round utilization of the resources of the firms doing construction, as well as agencies exercising engineering control over the construction, produces economic benefits. The magnitude and distribution of these gains can be accurately assessed only by detailed studies of the organizational setups and operational systems of said firms and agencies.

3. The excavation, placement and compaction of soils at low temperatures and high moisture contents is effectively prevented by current state specifications. In order to provide a rational basis for liberalizing the specifications, both laboratory and field experimentation . in order. The laboratory phase would quantify the effects of low temperature and high moisture on soil properties and characteristics, and the field phase would test the performance of real highway sections in which the modified procedures[1] were followed.

1. For a partial listing of these, see page 45.

Thus, it is indicated that further combined efforts of several kinds of civil engineering specialties are required to justify and to develop cold weather earthwork technology for Indiana.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. AASHO, Road User Benefit Analysis for Highway Improvements, Committee on Planning and Design Policies, Informational Report, 152 pp., 1960.

2. Alaska State Highway Department, Personal Communication, Dec. 9, 1965.

3. Alberta Provincial Department of Highways, Personal Communication, November 29, 1965.

4. Anderson, Donald A., Design Soils Engineer, Iowa State Highway Commission, Personal Communication, November 1, 1966.

5. Arctic Institute of North America, "Local Acclimatization," The Arctic Basin, pp. 282-285, Recent.

6. Associated General Contractors and House Builders of Sweden, Vagbyggande Aret Runt (Eliminating Seasonal Variations in Road Construction), Byggnadsindustrins Forlags AB, 187 pp., 1963.

7. Baker, Robert F., and Gray, Hamilton, "Design of Foundations, Embankments, and Cut Slopes," Highway Engineering Handbook, Edited by K. B. Woods, McGraw-Hill Book Company, Chapter 11, 1960.

8. Baladi, G. Y., Stress Distribution Within and Under Long Elastic and Visco-Elastic Embankments, Ph.D. Thesis, Purdue University, probably August 1967.

9. Ballenger, C. P., Jr., Ballenger Paving Company, Personal Communication, May 5, 1966.

10. Bauer, Hank J. and Wiersma, Dan, Forage Farm Soil Moisture During the 1962 Season, Purdue University, Agricultural Experiment Station Project 823, Research Project Report 66, 2 pp., April 1963.

11. Belcher, D. J., A Field Investigation of Low Cost Stabilized Roads, Purdue University Engineering Experiment Station, Research Series 81, Vol. 25, No. 2A, April 1941.

12. Berns Construction Company, Personal Communication, January , 1966.

13. Berus, Robert F., McMahan Construction Company, Personal Communication, February 18, 1966.

14. Blatt, Sidney, Holloway Construction Company, Personal Communication, January 1966.

15. Bloom, Marvin J., An Analysis of the Highway Frost Problem in the North Central United States, M.S. Thesis Purdue University, 171 pp., 1965.

16. Boileau, G. G., National Research Council of Canada, Personal Communication, February 8, 1966.

17. Bruce, W., Man and His Thermal Environment, National Research Council of Canada, Division of Building Research Technical Paper 84, 164 pp., February 1960.

18. Calumet Paving Company, Personal Communication, January 1966.

19. Carson, A. Brinton, General Excavation Methods, F. W. Dodge Corporation, 392 pp., 1961.

20. Chivers, Douglas A., Grading Engineer, Manitoba Provincial Highway Department, Personal Communication, November 23, 1965.

21. Conway, H. McKinley, Jr., The Weather Handbook, Conway Publications, Inc., 255 pp., 1963.

22. Corps of Engineers, Technical Manual 5-349, Arctic Construction, 328 pp., February 1962.

23. Davis, Jim, Jr., Jay Fox Construction Inc., Personal Communication, January 1966.

24. Dixon, Edwin M., Harbert Construction Company, Personal Communication, May 13, 1966.

25. Dreveskracht, W. W., Chief Soils Engineer, State of Minnesota Department of Highways, Personal Communication, November 16, 1965.

26. Dykins, F. A., Engineer of Materials, State of Illinois Division of Highways, Personal Communication, October 31, 1965.

27. Engineering Construction Corporation, Personal Communication, January 1966.

28. Engineering News Record, "Road Officials Eye Safety Standards," Engineering News Record, Vol. 177, No. 13, pp. 33-34, September 29, 1966.

29. Flaate, Kaare, Norwegian Road Research Laboratory, Personal Communication, May 24, 1966.

30. Flint, R. F., Glacial and Pleistocene Geology, John Wiley and Sons, 553 pp., 1957.

31. Folk, Charles L., "Highway Construction Under Winter Conditions," Constructor, Associated General Contractors of America, pp. 38-51, December 1966.

32. Fox, Lehman B., Materials Engineer, Montana Highway Commission, Personal Communication, November 18, 1965.

33. Frye, Frederick F., "Effect of an Expressway on Distribution of Traffic and Accidents", Highway Research Board, HRB, Vol. 21, pp. 90-105, 1963.

34. Gal'perin, M. I., Torgonenko, E. A., and Degtiarev. A. P., Excavation of Frozen Ground, SIPRE Translation 53, 4 pp., 1955.

35. Gervais, G. A., Materials Engineer, Nova Scotia Provincial Department of Highways, Personal Communication, December 13, 1966.

36. Green Construction of Indiana, Inc., Personal Communication, January 1966.

37. Gregg, L. E., "Earthwork," Highway Engineering Handbook, Edited by K. B. Woods, McGraw-Hill Book Company, Chapter 14, 1960.

38. Groves, S. J., and Sons Company, Personal Communication, January 1966.

39. Gunsaullus, L. H., and Son, Inc., Personal Communication, January 1966.

40. Hardaway, B. H., III, Hardaway Contracting Company, Personal Communication, May 9, 1966.

41. Henry, Jim, Hyde Construction Corporation, Personal Communication, June 2, 1966.

42. Hobart, T. F., Southern Amiesite Asphalt Company, Personal Communication, May 6, 1966.

43. Hoch, I., "Accident Experience: Expressways vs. Arterials," Chicago Area Transporation Study, 1959.

44. Hofmann, William P., Personal Communication to A. W. Johnson on effects of freezing temperatures on compaction, March 1, 1961.

45. Hofmann, William P., Bureau of Soil Mechanics, New York State Department of Public Works, Personal Communication, November 16, 1965.

46. Hogentogler, C. A., and Willis, E. A., "Stabilized Soil Roads," Public Roads, Volume 17, No. 3, pp 48-50, May 1936.

47. Huffman, John E., Engineer of Soils, State Highway Commission of Kansas, Personal Communication, November 30, 1966.

48. Idaho State Highway Department, Personal Communication, December 6, 1965.

49. Indiana Employment Security Board, Indiana Employment Security Act, 118 pp., 1965.

50. Indiana State Highway Commission, Subgrade Investigation Reports for Projects: I64-1(2)0, I64-1(3)7, I70-2(3)49, I65-7(1)200, I70-1(18)12, I64-1(10)26, S-823(1), S-310(3), S-219(3), S-606(7), and others.

51. Johnson, A. W., and Sallberg, J. R., Factors Influencing Compaction Test Results, HRB Bull. 319, pp. 49-52, 1962.

52. Jonson, Jan-Ake, The National Swedish Institute of Building Research, Personal Communication, April 1, 1966.

53. Kastner, E., Contracting and Material Company, Personal Communication, January 1966.

54. Kellett, J. E., District Engineer, Yukon Territory Department of Public Works, Personal Communication, November 24, 1965.

55. Kirk, W. D., Jr., Wright Contracting Company, Personal Communication, May 19, 1966.

56. Koltnow, Peter G., "Travel Time Study," California Highways and Public Works, Volume 46, Nos. 1-2, pp. 41-43, January-February 1967.

57. Kreiling, Staff Construction Engineer, Colorado State Highway Department, Personal Communication, December 9, 1965.

58. Larocque, Guy S., Assistant Manager of Geology Service, Hydro-Quebec, Personal Communication, September 10, 1966.

59. Lee, Robert R. and Grant, E. L., "Inflation and Highway Economy Studies," Highway Research Record, HRB, Vol. 100, pp. 20-37, 1965.

60. Linell, K. A., "Frost Action and Permafrost," Highway Engineering Handbook, Edited by K. B. Woods, McGraw-Hill Book Company, Chapter 13, 1960.

61. Long, Erwin L., Corps of Engineers, Alaska District, Chief, Soil Design Section, Personal Communication, March 18, 1966.

62. Long, Nimrod W. E., Warren Brothers Roads Company, Personal Communication, May 10, 1966.

63. Lovell, C. W., Jr., "Temperature Effects on Phase Composition and Strength of Partially-Frozen Soil," Fundamental and Practical Concepts of Soil Freezing, HRB Bulletin 168, pp 74-95, 1957.

64. Mackie, John C., Field Manual of Soil Engineering, Michigan State Highway Department, pp 209, July 1960.

65. Maine State Highway Commission, Personal Communication, November 16, 1965.

66. Matthews, A. E., Engineer of Soils, State of Michigan Highway Department, Personal Communication, November 17, 1965.

67. McClimon, Alan S., "Off-Highway Hauling," Handbook of Heavy Construction, Edited by F. W. Stubbs, McGraw-Hill Book Company, Chapter 3, 1959.

68. McDonald, E. B., Materials Engineer, State of South Dakota Department of Highways, Personal Communication, November 17, 1965.

69. McGregor, Duncan J., Gravels of Indiana, Indiana Department of Conservation, Report of Progress 17, 53 pp., 1960.

70. Michael, Harold L., "$300 Million Road Accident Loss Predicted," The Indianapolis Star, p. 25, September 29, 1965.

71. Michael, Harold L., "Highway Safety, Fables and Facts," Backgrounder Purdue University Schools of Engineering, June 1966.

72. Mickleborough, B. W., Soils Engineer, Province of Saskatchewan Department of Highways and Transportation, Personal Communication, January 17, 1966.

73. Miller Brothers Inc., Personal Communication, January 1966.

74. Missouri State Highway Department, Personal Communication, November 2, 1966.

75. Moley, Raymond, "Automobile Safety-III," Newsweek, Vol. 67, No. 6, p. 88.

76. Moss, J. P., Moss Thornton Company, Inc., Personal Communication, May 18, 1966.

77. National Safety Council, Accident Facts, 1966 Edition, 96 pp., 1966.

78. Nebraska State Highway Department, Personal Communication, November 7, 1966.

79. Neu, Fredrick W., Southeastern Paving Company, Personal Communication, May 5, 1966.

80. O'Connor, J. C., and Sons, Inc., Personal Communication, January, 1966.

81. Olinger, Lee Ray, Olinger Construction Company, Personal Communication, January 1966.

82. Pennsylvania State Highway Department, Personal Communication, October 31, 1966.

83. Perloff, W. H., Baladi, G. Y., and Harr, M. E., "Stress Distribution Within and Under Long Elastic Embankments," Proceedings, HRB, 1967.

84. Peter Kiewit Sons Company, Personal Communication, January 1966.

85. Prahl, C. G., Director of Highways, Washington State Highway Commission, Personal Communication, December 3, 1965.

86. Ralph Myers Contracting Corporation, Personal Communication, January 1966.

87. Readshaw, E. E., Senior Materials Engineer, British Columbia Provincial Department of Highways, Personal Communication, December 16, 1965.

88. Rock Road Construction Company, Personal Communication, January 1966.

89. Ryhre, Gunnar, Associated General Contractors and House Builders of Sweden, Personal Communication, April 6, 1966.

90. Samson, Laval, Chief Engineer, Terratech Limited, Personal Communication, December 9, 1965.

91. Schneider, Allan F., "Physiography", Natural Features of Indiana, Edited by Alton A. Lindsey, Indiana Academy of Science, Chapter 3, 1966.

92. Shepard, C. H., Materials Engineer, Ohio Department of Highways, Personal Communication, January 5, 1966.

93. Sherard, James L., Woodward, Richard J., Gizienski, Stanley F., and Clevenger, William A., Earth and Earth-Rock Dams, Wiley, pp 631-633, 1963.

94. Sielski, M. C., "What the Northwest Expressway Will Mean to Chicagoland Motorists," Chicago Motor Club, 1960.

95. Slesser, Charles, The Migration and Effect on Frost Heave of Calcium Chloride in Soil, Purdue University Engineering Bulletin 89, Highway Research Bulletin 11, 168 pp., July 1943.

96. Smith, G. W., Soils Analyst, Newfoundland Provincial Department of Highways, Personal Communication, December 2, 1965.

97. Spears, Donald G., Spears-Dehner, Inc., Personal Communication, January 1966.

98. Stapp, R. G., Superintendent and Chief Engineer, Wyoming State Highway Commission, Personal Communication, November 23, 1965.

99. Stone City Construction Company, Personal Communication, January 1966.

100. Teer, Nello L., Jr., Nello L. Teer Company, Personal Communication, May 12, 1966.

101. Thornthwaite, C. W., Mather, John R., and Carter, Douglas B., 3 Water Balance Maps of Eastern North America, 47 pp., Resources for the Future, Inc., November 1958.

102. Tolman, C. F., Groundwater, McGraw-Hill Book Company, 594 pp., 1937.

103. Topp, J. B., Materials Engineer, Province of New Brunswick Department of Public Works, Personal Communication, November 19, 1965.

104. Tregaskes, H. A., Construction Engineer, Ontario Provincial Department of Highways, Personal Communication, December 8, 1965.

105. Tressier, G. Robert, Soils and Materials Engineer, Quebec Provincial Department of Roads, Personal Communication, November 17, 1965.

106. Tri-Angle Construction Company, Inc., Personal Communication, January 1966.

107. United States Department of Agriculture, "Precipitation and Humidity," Atlas of American Agriculture, March 1922.

108. United States Department of Agriculture, "Soils and Men," Yearbook of Agriculture, 1938.

109. United States Department of Commerce, Climatological Data, Weather Bureau, Vol. 65, No. 1, January 1960, through Vol. 70, No. 3, March 1965.

110. United States Department of Commerce, "Summary of Hourly Observations", Evansville, Indiana, 1951-1960; Fort Wayne, Indiana 1951-1960; Indianapolis, Indiana, 1951-1960; South Bend, Indiana, 1956-1960, Climatography of the United States No. 82-12, Weather Bureau, 15 pp. each, 1963.

111. United States Department of Commerce, World Weather Records 1941-1950, Weather Bureau, 1361 pp., 1951.

112. United Stated Department of Labor, Employment and Earning Statistics for States and Areas 1939-1965, Bulletin 1370-3, 740 pp., June 1966.

113. Vermont Highway Department, Personal Communication, December 6, 1965.

114. Verville, Martin J., Soils Engineer, State of New Hampshire Department of Public Works and Highways, Personal Communication, December 3, 1965.

115. Visher, S. S., Climatic Atlas of the United States, Harvard University Press, 403 pp., 1954.

116. Wayne, William J., Thickness of Drift and Bedrock Physiography of Indiana North of the Wisconsin Glacial Boundary, Indiana Department of Conservation Geological Survey, Report of Progress 7, 70 pp., June 1956.

117. Wheeler, W. M., J. A. Jones Construction Company, Personal Communication, May 18, 1966.

118. Wiersma, Dan and Bauer, Hank J., Forage Farm Moisture During the 1963 Season, Purdue University Agricultural Experiment Station Project 823, Research Project Report 132, 4 pp., April 1964.

119. Wiersma, Dan and Bauer, Hank J., The 101-Day Soil Moisture Storage at the Southern Indiana Forage Farm, Purdue University Agricultural Experiment Project 1381, Research Progress Report 185, 3 pp., April 1965.

120. Wisconsin State Highway Department, Personal Communication, November 1965.

121. Wold, Candins A., Soils Engineer, North Dakota State Highway Department, Personal Communication, November 20, 1965.

122. Yarbrough, F., Soils Engineer, Oregon State Highway Department, Personal Communication, December 4, 1965.

123. Yoakem, Delmar, A Survey of Winter Construction Practices Earthwork, Concrete and Asphalt, CRREL Special Report 76, 144 pp., July 1966.

APPENDIX A

APPENDIX A

COLD WEATHER EARTHWORK QUESTIONNAIRE
TO HIGHWAY DEPARTMENTS

1. Does your department permit and/or encourage the excavation of frozen ground during the winter months?

   a. If so, what thicknesses of frozen ground do contractors under your supervision excavate?

   b. What methods are used to do this excavation? What machines and techniques?

   c. What does your department permit excavated frozen soil to be used for?

   d. Has frozen soil placed under your department's supervision performed satisfactorily?

2. What conditions (temperature, depth of snow, etc.) determine the end of the earthwork season (placement and/or excavation) under your department's supervision?

   a. What are the normal beginning and ending dates for construction under your department's supervision?

3. Does your department permit any placement and/or compaction of soils when the air temperature is below freezing?

    a. If so, is it necessary or possible to adjust the water content of these soils?

    b. What equipment and methods are used to place and compact these soils?

    c. Do soils so placed perform satisfactorily in service?

    d. What methods are used to check densities and/or moisture contents of these soils placed and compacted when the air temperature is below freezing?

4. Additional experience which you have had with any type of cold weather earthwork.

APPENDIX B

APPENDIX B

COLD WEATHER EARTHWORK QUESTIONNAIRE TO CONTRACTORS

1. Have you had any experience in excavating frozen ground?

   a. If so, what thicknesses of frozen ground have you excavated?

   b. What methods were used in this excavation? How successful were these methods?

   c. What did you use the excavated frozen soil for? Did it perform satisfactorily?

2. What conditions usually cause you to shut down for the winter?

3. What conditions determine when you can start up again in the spring?

4. What economic factors prevent you from doing earthwork in the winter?

5. Have you ever kept records of what your actual increased costs of doing earthwork in the winter were?

6. What incentives would cause you to do earthwork all winter?

APPENDIX C

APPENDIX C

INFLUENCE OF TEMPERATURE ON COMPACTION OF SELECTED INDIANA SOILS

To determine the influence of temperature on the compaction of Indiana soils, laboratory testing was carried out on two soils which are common in northern Indiana. Maumee "B", the B horizon of the Maumee Sandy Loam (derived from the Maumee outwash-lacustrine plain deposit) was selected to represent relatively clean granular soils. Miami "B", the B horizon of the Miami Loam (derived from glacial till) was selected to represent predominantly fine grained Indiana glacial tills. The index properties of these two soils are shown in Table 13.

Table 13

Index Properties and Classification of Maumee "B" and Miami "B" Soils

Soil	w_L	w_P	I_p	% Silt and Clay	AASHO Classification
Maumee "B"	-	-	NP	5	A - 3
Miami "B"	23	16	7	50	A - 4 (8)

For the Miami "B" soil 98% passed the #4 sieve and was used for the compaction tests. All of the Maumee "B" soil passed the #10 sieve. To approximate field conditions, the soils were not allowed to dry to any water content lower than that at which they were compacted.

In order that a considerable number of tests could be performed with the soil available, the Harvard miniature apparatus was used. Each mold was filled with 5 layers of equal height. Each layer was compacted with 25 tamps of approximately 1 second duration, with the 40-pound spring. Standard AASHO compaction tests run on the same soils showed that the procedure used with the Harvard miniature apparatus gave peak densities equal to or slightly greater than the Standard AASHO maxima.

The tests were performed in a walk-in cold room or in a large oven to control the temperature of all elements involved. Before each run, all equipment and the soil (mixed to the desired water contents and placed in sealed containers), were brought to the test temperature. Temperature was closely controlled to ± 0.1°C. Compaction tests were performed at 1.7°C (35°F), 20.6°C (69°F), 49.5°C (121°F), and 54.5°C (130°F)...which were convenient temperatures settings. In addition, a number of tests were performed at temperatures below freezing. The later densities were very low, erratic, and are not reported.

The results of the compaction tests performed at temperatures above freezing are shown in Figures 16 and 17. Unlike the data of Figure 2 (page 9) which showed that lower temperatures result in significantly lower densities, a wide variation in above-freezing temperatures for these two Indiana soils had little effect on density. The highest densities resulted at intermediate temperatures.

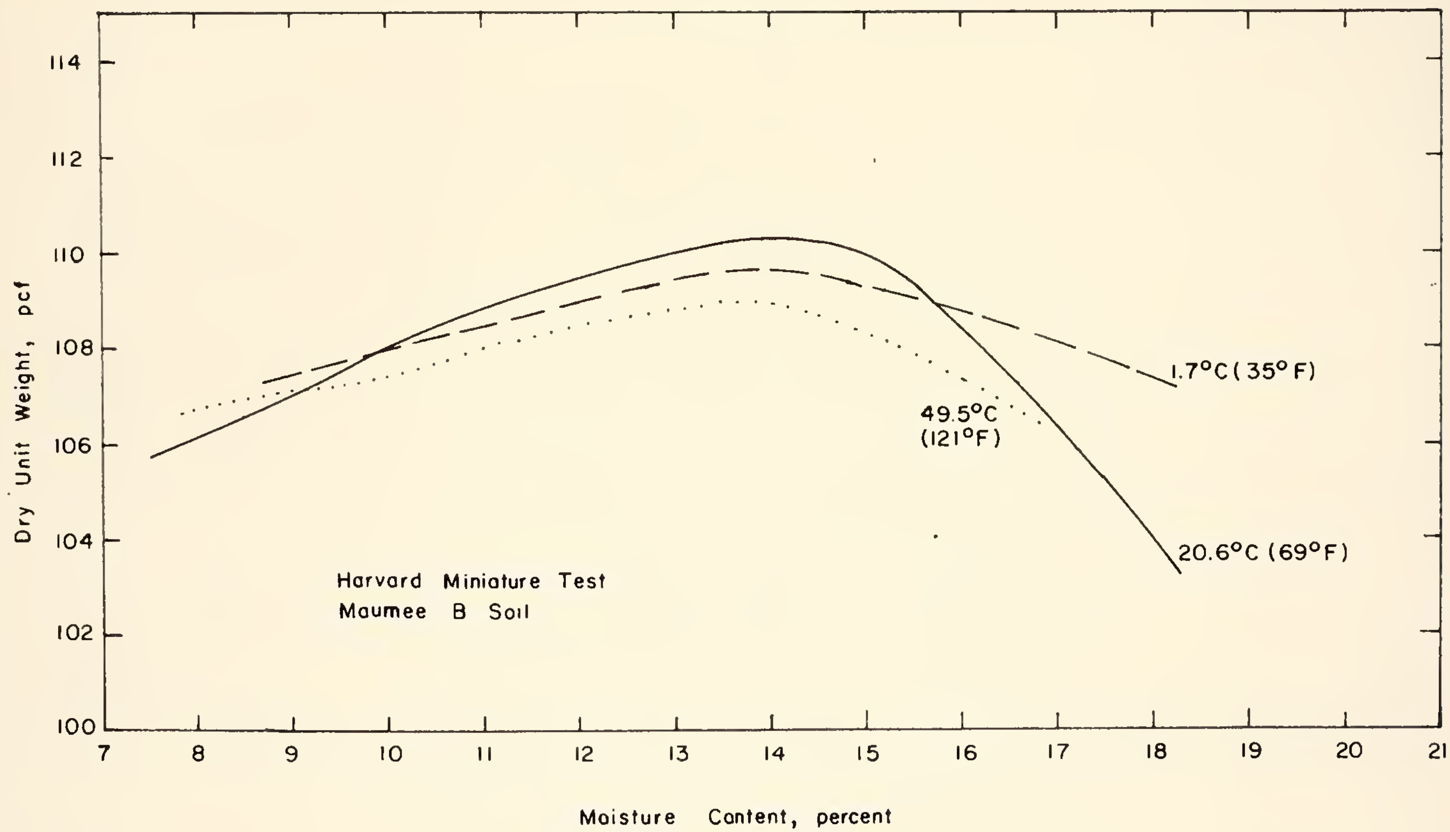


Figure 16 Influence of Temperature on Compaction — I

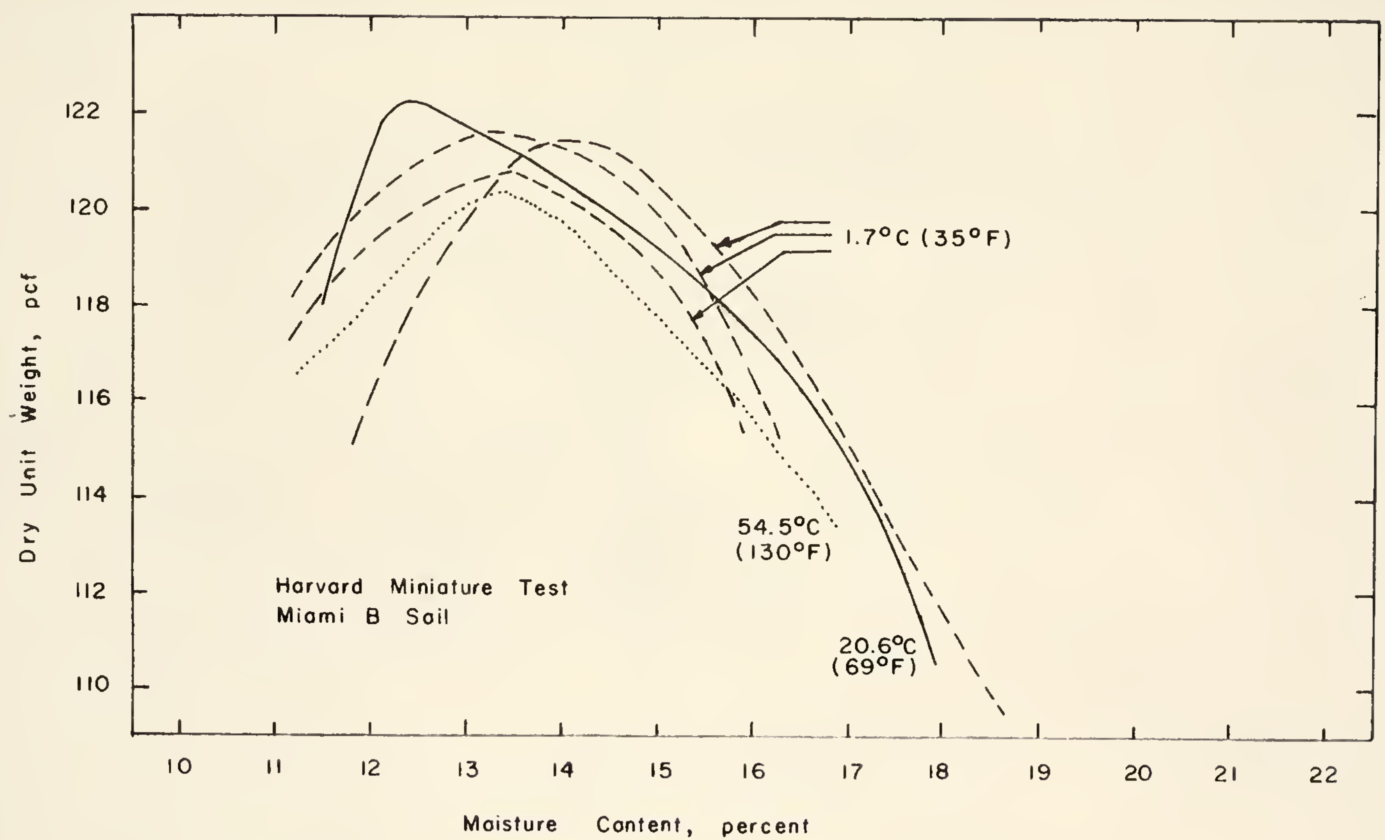


Figure 17 Influence of Temperature on Compaction — II